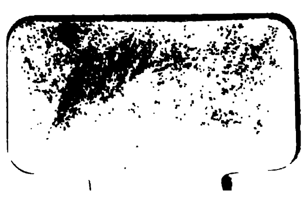
ON
SIMPLE & COMPOUND ENGINES

NIEL M^{c} DOUGALL.
A.I.C.E. M.I.N.A.



THE RELATIVE MERITS OF

SIMPLE

AND

COMPOUND ENGINES

AS APPLIED TO SHIPS OF WAR.

Prize Essay,

BY

NIEL M^c DOUGALL,

ASSOCIATE OF THE INSTITUTION OF CIVIL ENGINEERS, AND MEMBER OF THE INSTITUTION OF NAVAL ARCHITECTS; OF THE DEPARTMENT OF THE CONTROLLER OF THE NAVY, ADMIRALTY, WHITEHALL.

With an Appendix by the Author,

CONTAINING PARTICULARS AND ANALYSES OF RECENT EXPERIMENTS.

GRIFFIN & CO.,

(Publishers, by Appointment, to H.R.H. the Duke of Edinburgh.)

15, COCKSPUR STREET, PALL MALL, LONDON. | AND 2, THE HARD, PORTSEA, PORTSMOUTH.

1875.

PRINTED AT THE OFFICE OF THE PUBLISHERS.

"INSCIENS SCIENTIA."

TO the writer of this Essay was awarded the prize of £20, offered in the early part of last year by the JUNIOR NAVAL PROFESSIONAL ASSOCIATION, for the best Essay on "The Relative Merits of Simple and Compound Engines as "applied to Ships of War." The following were the terms upon which competition was invited :—

I.—Competition is open to all.

II.—The Essays must be rendered to the Hon. Sec., care of Messrs. GRIFFIN & Co., Portsea, before the 1st August, 1874.

III.—The Essays to be strictly anonymous, but each to have a motto and to be accompanied by a sealed envelope, with the motto outside and the name of the competitor inside. It is desirable that the Essay should not exceed 100 pages of the size of the "Proceedings" of the Association.

IV.—The Essays will be submitted for decision to Professor COTTERILL, M.A., Professor of Applied Mechanics, Royal Naval College, Greenwich; Chief Inspector WILLIAM EAMES, R.N., the Chief-Engineer of H.M. Dockyard, Chatham; and JOHN PENN, ESQ., F.R.S., Greenwich.

V.—The Essays will become the property of the Association, to publish if desirable.

PREFACE.

In competing for the Prize which this Essay has secured, the writer was not in a position to use data connected with the Navy other than might be accessible to competitors not in the Admiralty service. Particulars of interest not before published have, however, by permission, now been added.

There are conclusions to be drawn from a study of the history of the compound engine in the Navy upon which it is obviously impossible for a servant of the Admiralty to speak with perfect freedom. There is one however which may here with propriety be indicated. The dangerous lengths to which purely theoretical views may be carried in the pursuit of a chimerical perfection in some single direction in the treatment of mechanical questions was remarkably exemplified in the late Professor RANKINE'S advocacy of the complicated six-cylinder compound engines of the *Constance*, as examples of successful Naval engineering. As compared with other machinery, space, weight, simplicity, facility of handling, and facility for repair had been sacrificed in these engines, but a nearly perfect "balance of driving forces" had been secured, a possible saving of fuel had thus been effected, and the engines were therefore models in the estimation of Professor RANKINE, undoubtedly the greatest master of abstract science as applied to constructive art, in the Committee on Admiralty Designs.

It is pretty certain that if a Commander took a ship engined in this way into an action, such as all experience gained since the date of the *Constance* teaches us must be expected in any future war, he would be as likely to prove dangerous to a friend as to an enemy, and the probabilities of his ever bringing her out again would certainly not be great.

The broad practical view which the most eminent English mechanicians as a rule have taken in selecting means to attain special ends has placed their work in point of trustworthiness

and general fitness far above that of the engineers of other countries. It is the conviction that a departure of considerable moment from our traditionary practice has been made in the adaptation of commercial machinery to our fighting ships which has chiefly weighed with the writer in penning this essay, and he has endeavoured to treat his subject in such a manner as to make it intelligible as far as possible to non-technical readers.

The term "commercial" is applied throughout to that form of the compound engine having inter-dependent cylinders of unequal diameter. It is the form which, arranged in various ways, has been in general use for a number of years in the Commercial Marine and for some time back adopted for ships of all classes in the Navy. The term is used in order to distinguish this type of engine from the compound engines of the French Navy, and from engines of the "composite" form capable of being worked either as simple expansive engines or as compound engines, a set of engines of which type, as will be seen in the appendix, the eminent firm of Messrs. JOHN PENN & SON have now in hand.

The writer has much pleasure in taking this opportunity of thanking the many Engineers in the Admiralty Service and outside it, who have kindly furnished him with valuable information; and of expressing especially his gratitude to his friends in the French and American Navies for the freedom with which they have favoured him with their opinions and for the courtesy with which they have supplied information.

It is hoped that the conclusions arrived at, and the facts and figures by which they are supported, may help to the solution of a question which is of importance to all interested in the use of steam.

SCIENTIFIC CLUB, LONDON, W.
APRIL, 1875.

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THE RELATIVE MERITS

OF

Simple and Compound Engines.

CHAPTER I.

POPULARITY OF THE COMPOUND ENGINE.

THE real importance to the Navy of the subject selected by the *Junior Naval Professional Association* for discussion will probably be evident but to few at first sight, and in view of the overwhelming evidence of the favour with which the Compound Engine has for some time been regarded, it must, in the minds of experienced engineers, argue great attention to the duties of their position, that the Committee of so unpretentious an Association should have looked beneath the surface and have treated the subject as a legitimate question for debate.

Since the submission of the Report of the Committee on Admiralty Designs, in July, 1871, the compound engine has been adopted for ships of every class in the British Navy; for a number of years a special type of it has been in use in the French Navy; to commercial ships of modern build it is all but universally applied; and, following the example of the British Government—Russia, and to some extent America and other Foreign Powers have been adopting this type of engine in their newest war ships. Former opponents to it appear for some time to have yielded to the weight of opinion in its favour, and to have

tacitly admitted the expediency of adopting an engine whose superior efficiency as a propelling agent has become so generally believed in. Recently conspicuous, however, in his opposition to its use, as ordinarily fitted for fighting ships, has been the late Chief-Constructor of the Navy, MR. E. J. REED, C.B., M.P., to whose mastery of the details of the complicated structures his genius originated, has no doubt been due that perfection of design and execution which enabled this country to take the lead in the construction of ships of war. But the evidence of MR. REED before the Committee on Admiralty Designs was not on the whole unfavourable to the engine, and DR. WOOLLEY, now Joint-Editor with MR. REED of *Naval Science*, was one of the leading scientific members of the Committee who, although anything but unanimous on many of the subjects discussed, appear at all events to have agreed in recommending the exclusive adoption of the compound engine in the Navy.

In a recent article, however in *Naval Science*, which will be quoted in this essay, the unfitness of the commercial type of compound engine for purposes of war is dwelt upon at some length, and the superior efficiency, in a fighting sense, of simple engines strongly insisted on. Intimately connected for a long period of years as the two eminent Editors have been with mechanical science in the Navy, their opinion upon such a subject is undoubtedly entitled to the greatest respect, but on the other hand, prominent among the Members of the Committee in his advocacy of the inherent superiority of the compound engine, was the late Professor RANKINE, whose loss to science has been so universally deplored, and who had from a theoretical point of view made the subject of heat and the steam engine peculiarly his own. His acquaintance with the special machinery required for a modern ship of war appears to have been very limited, however, and

his expressed opinions, (which will be quoted in due course,) upon some of the questions raised in connection with this subject, show that he had but very partially mastered the intricate problem which the Committee, whom, in this matter as in others, he appears in a great measure to have led, confidently considered they had solved.

CHAPTER II.

THE PROPELLING MACHINERY OF WAR SHIPS AS GENERALLY AFFECTED BY THE DEVELOPMENT OF THE ART OF ATTACK.

It is not necessary for the purposes of this essay to consider at any length the expediency of retaining the doubtful protection of vertical side armour in view of the great development of the art of attack, nor to attempt to attach their relative values to the gun, ram, and torpedo as means of attack. The most competent authorities are not agreed upon these questions, but it is at least agreed on all hands that the preservation of the motive power intact in an action is essential to the life of the ship. The probable course of a future Naval battle was vividly sketched by Commander Bridge, R.N., in a paper read some time ago at the Royal United Service Institution.

After describing the approach of the two hostile fleets under the heaviest bow fire which could be maintained until the ships would be within striking distance, Commander Bridge says: "Now will come the doubly anxious moment of seeking to ram "one's antagonist; to avoid being rammed by her; to steer "clear of her towed torpedo; and to plant one's own torpedo "conveniently under her water-line. About this moment, too, "the ships of that fleet which is not in 'line abreast' may fire "one or both converged broadsides; the fleet that is so formed

"will be precluded from having recourse to that, probably still "advantageous, proceeding. In the early stage of an action, "whilst heads are still cool and formations still to a certain "extent kept, I venture to think no great damage will be done "on either side. I do not mean that no ship will be hit by "shot, or even that none will be destroyed by either ram or "torpedo. What I do mean, is that no fleet as a whole, will, "in my opinion, suffer any serious diminution of its strength at "first. The two, I expect, will pass through one another to a "great extent intact, till there shall arrive the time which shall "be the crucial test of the value of the evolutionary practice "of peaceful times. The two fleets will have to re-form and "prepare for a second encounter, much resembling that which "has just taken place. To paraphrase the remark of a dis-"tinguished General, 'Now is the time for the reserve "squadron.' Picture to yourself the effect, moral as well as "material, of a well-ordered column of fresh ships bearing down "at superior speed upon a group of vessels endeavouring to "re-form after passing through an encounter such as I have "attempted to describe. Should any vessel have received no "other damage than the disabling of her machinery, she will "yet be at the mercy of any that, still possessing the power of "motion, may be ordered to cannonade or ram her; and, "refusing to strike, may, as she lies motionless, be conveniently "disposed of by one of MR. WHITEHEAD's torpedoes, which may "be not inaptly termed the successors of the old fire ships."

Nothing can possibly be more evident than that mobility is the chief requisite either for attack or defence, and that the temporary disablement of the propelling machinery almost necessarily implies defeat. The question then arises, can the machinery of an iron-clad be considered as secure from the effects of projectiles when the sides of the ship are being battered at point blank range by shot from the monstrous guns now in

course of construction? If the protection of the armour could be depended upon, no special precautions would be needed in the design and arrangement of the machinery to guard against its complete failure when under fire, and, so far as provision against disablement goes, the propelling machinery of a modern fighting ship need not be dissimilar in character from that of vessels of the commercial marine, which have only wind and tide to contend against. We have it, however, on the authority of MR. BARNABY, the Chief Naval Architect to the Admiralty, that in the *Inflexible*, with 24 inches of armour, we have already practically reached the limit of thickness of armour which can be carried on sea-going ships, and we know that even by the time she is afloat, in all probability, guns will have been made which will be capable of piercing her sides as easily as those of her comparatively thinly-armoured consorts could be penetrated by shot from guns already in existence.

MR. BARNABY says with reference to the *Inflexible*: "This is " the ship which the progress of invention in artillery has finally " driven us to resort to. Had the manufacture of enormous " ordnance been stopped when the 35-ton gun was introduced, " we might have been satisfied with the *Fury*, with her guns of " this nature and her 14-inch armour; but English artillerists " were ready to make guns of twice 35-tons, and foreign powers " were known to be building ships to receive such guns."

" There can be no question that we could not allow foreign " seamen to have guns afloat more powerful than any of our " own, however ready we might have been to allow them to " defend themselves with thicker armour. Although, therefore, " it was known that the ships in which these guns were to be " mounted were to be protected by 22 inches of armour, thick- " ness of armour was not made a ruling feature of the design " of the first-class ship, which was to mark the next step in

"advance upon the *Fury*; but the first of the ruling conditions "was that she should be able to mount the heaviest guns "which could possibly be made now, and by some easy "modifications in her construction hereafter, guns of twice "that weight when they can be manufactured."

Foreseeing also the rapid approach of the time when the gun would at length become victorious, SIR WILLIAM ARMSTRONG, ADMIRAL ELLIOT and others who are in every way qualified to express an opinion, have recommended the disuse of side armour, and in view of the danger to comparatively slow unwieldy ships from attack by ramming and the torpedo, they have advocated the construction of ships of great speed, fitted as rams, armed with the torpedo, and mounting guns capable of piercing the sides of any iron-clad afloat, armour being used only where it could be applied for deflecting shot, as at the bow and on decks under the water-line.

In view of these considerations, we have, with regard to the propelling machinery for ships intended to fight at close quarters, plainly the following conditions :—

FIRST.—The sustained efficiency of the motive power under fire, and the development of high speed with the object of securing the greatest possible facility for manœuvring in an action, are above all things essential to the attainment of success in any future naval engagement.

SECOND.—Even the most heavily armoured of the ships already built or building may be opposed to an enemy carrying guns capable of piercing, or at all events of partially penetrating, the armour provided for the protection of the machinery; the effect of partial penetration being frequently most disastrous on account of the displacement of great masses of backing, etc., which would be hurled among the machinery.

THIRD.—As the protection of the armour cannot be

depended upon, and as even momentary loss of the propelling power might be fatal, it is most important that the machinery itself should be so arranged as to reduce the chances of disablement to a minimum.

In unarmoured or but partially armoured cruisers, it is also most important that the design of the machinery should be such as to secure the greatest attainable efficiency under fire.

CHAPTER III.

RECOMMENDATION OF THE COMMITTEE ON ADMIRALTY DESIGNS.

IN considering the recent adoption on so extensive a scale, of the high-pressure compound engine in our own Navy, the manner in which its inherent unfitness for purposes of war was overlooked by the Committee on Designs, in recommending its exclusive adoption, is most striking. The Committee, after duly weighing the evidence brought before them, recommended to the Admiralty the adoption of the engine in the following terms: "The carrying power of ships may certainly "be to some extent increased by the adoption of 'Compound' "Engines into Her Majesty's Service. We are aware that this "modification of the ordinary marine engine has not escaped "the notice of the Constructive Department of the Navy, and "that some few of Her Majesty's ships have been so fitted. "But its use has recently become very general in the Mercan- "tile Marine, and the weight of evidence in favour of the "large economy of fuel thereby gained is to our minds over- "whelming and conclusive. It is unnecessary for us to say "that in designing a ship, economy of fuel may mean either "thicker armour, greater speed, a smaller and cheaper ship, or

"the power of moving under steam alone for an increased "period, according to the service which the ship is intended to "perform. We beg leave, therefore, earnestly to recommend "that the use of compound engines may be generally adopted "in ships of war hereafter to be constructed, and applied, "whenever it can be done with due regard to economy and to "the convenience of the Service, to those already built.

"In designing engines of this kind, care should be taken "to diminish friction as far as practicable by attending to the "balance of forces upon the shaft. In applying them to ships "of war attention must also be paid to so disposing the parts "as to keep the whole at as low a level as possible."

The general introduction of the engine is here urged purely upon the ground of its supposed great superiority in economy of fuel, the evidence of this superiority being in the minds of the Committee "overwhelming" and "conclusive." Before discussing the relative merits of the two types of engine in point of efficiency under fire, it will be necessary, among other things, to examine some of the grounds upon which the Committee formed their opinion, and to see how far recent experience has justified their conclusions. It will be expedient to treat the question of relative economy of fuel of the engines under two heads: 1st, "Efficiency of the steam," and 2nd, "Efficiency of the mechanism."

CHAPTER IV.

RELATIVE EFFICIENCY OF THE STEAM IN SIMPLE AND COMPOUND ENGINES.

THE first compound engine was designed by HORNBLOWER in 1781. This was a single-acting pumping engine, and the principle was afterwards applied to double-acting engines with WATT'S separate condenser, by WOOLF. Although not now commonly connected with his name among engineers in this country, the compound engine is still very generally spoken of as *La Machine de Woolf* in France. Various modifications of the engine have been introduced at different dates by McNAUGHT, CRADDOCK, NICHOLSON, HUMPHRYS, RANDOLPH, ELDER and Co., and many others. The principle was first successfully applied to marine engines by Messrs. RANDOLPH, ELDER and Co., who in 1854 fitted a set of compound engines with four cylinders, to the screw-steamer *Brandon,* and two years later, engines similar in principle were constructed by this firm for the *Valparaiso* and the *Inca,* paddle steamers of the Pacific Steam Navigation Company. The type of engine fitted in these steamers appears to be still adhered to by Messrs. ELDER and Co. for paddle steamers. For screw steamers they, however, in common with a large number of engineers in this country, have generally adopted for some years the well-known two-cylinder type of compound engine, which, fitted to the *Briton, Tenedos,* &c., has found most favour in our Navy. This form of the compound engine was first introduced by NICHOLSON, who in 1850 patented the arrangement under the name of "The Continuous Expansion Engine."

In originating the compound engine it was not claimed apparently that any other advantage was gained than that of the reduction of the maximum strains upon the mechanism, and at an early period it was recognised by the more intelligent of the compound engine-makers that a considerable loss of efficiency was incurred in the transmission of the steam from one cylinder to the other. Of late years it has, however, been claimed that the efficiency of the steam is on the whole greater in this than in the single-cylinder expansion engine, on account of the reduction of the range of temperature to which the cylinders are subject. In a paper published in *The Engineer* of March 11th, 1870, Professor RANKINE in summarising the advantages of compound engines says they possess an advantage in point of economy of heat and steam over the simple engine, because, " in a single cylinder engine it is necessary, in order to prevent " liquefaction and re-evaporation of the steam, and consequent " waste of heat, that the whole metal of the cylinder should be " kept by means of a steam-jacket, at a temperature equal to that " of the steam when first admitted; whereas, in a compound " engine it is the smaller, or high-pressure cylinder only which " has to be kept at so high a temperature, it being sufficient to " keep the larger or low-pressure cylinder at the temperature " corresponding to the pressure at which the steam passes from " the high to the low pressure cylinder."

Other authorities have also attached great importance to the reduction of the range of temperature in each cylinder, and it is undoubtedly the case that the high temperature at which the high-pressure cylinder is usually kept, conduces to economy by preventing the loss of initial pressure due to liquefaction of the steam on its entering the cylinder. That the gain due to this cause counter-balances the loss between the cylinders is, however, doubtful, as will be seen further on, and in practice the advantage pointed out by Professor RANKINE does not exist

at all in many of the most successful compound engines, as both cylinders are jacketed at the boiler-pressure; there being thus two cylinders kept at the highest possible temperature, the working steam in one of which must invariably have a far lower mean temperature than that of a single-cylinder engine working at the same total rate of expansion. Many other engines, the *Briton's* for example, have given very good results with the low-pressure cylinder only jacketed, while there are probably as many others which apparently work with equally good, or perhaps better results, with only the high-pressure cylinder jacketed. The utility of jacketing compound engines at all, in which the steam is but slightly expanded in each cylinder, appears to be doubtful, experience here corresponding with that gained with the old low-pressure engines, which were practically non-expansive, and in which the jacket was abandoned as unnecessary.

But little exact information is, however, available with reference to the quantity of steam used in the jackets and cylinders of engines of the rival types when worked at the same rate of expansion, and in the rough comparisons of the engines which are generally made, the compound engine is almost invariably worked at a higher pressure, and frequently with a greater capacity of cylinder, exclusive of the high-pressure cylinder, the greater economy which thus might be expected, being explained on some such recondite grounds as those quoted above.

It is not necessary here to recapitulate the unfortunate history of the compound engine in the Navy, previous to the use of steam at a pressure of 50lbs. and upwards. From one cause and another the engines were unsuccessful, and it was not until they were worked with steam at from 50lbs. to 60lbs. pressure, that the superiority of the engine, in point of economy

of fuel over simple engines of good design, worked at 30lbs., could be established. It can be shown that this superiority, so far as it can be fairly proved, is plainly due to the use of steam at higher pressure and greater expansion; and it can also be shown that there is reason to suppose that even better results in point of economy can be obtained with well-designed simple engines, when worked at the present working pressure of the compound engine, it having been already shown apparently so far as actual experiment has gone in the Navy, that they can be worked with *equal* economy.

The most economical result obtained with a simple engine in the Navy previous to the use of what is termed at present "high-pressure" steam, appears to have been that given by the *Octavia* in a competitive trial with the *Constance*, a ship fitted with compound engines, which will be referred to further on. The mean of three trials at 6, 8, and 10 knots, gave as a result 2·21 lbs. of coal used per indicated horse-power per hour, against 2·12 lbs. in the *Constance* tried at the same speeds, the ships being similar. As this was a competitive trial for the purpose of ascertaining the relative quantity of coal used in the two ships, no doubt great care was exercised in conducting the trial, so as to ensure the working of the engines with the greatest possible economy, but on the well-known six hours' runs, greater attention has generally been paid to the development of the greatest possible amount of power than to the production of an economical result. Thus, with regard to the trial of the *Sultan*, the result of which is tabulated below, it was stated in evidence before the Committee on Designs, that 13 per cent. of the coal was thrown overboard in the shape of clinkers and ashes, whereas, in the trials of the then newly-introduced high-pressure compound engines, showing great economy, the bulk, if not the whole of the ashes, were burnt over again.

—		When tried.	Steam pressure; lbs. per square inch above atmosphere.	I.H.P.	Volume swept per I.H.P. per min. by pistons.		Coal consumed per I.H.P. per hour.
					Cubic Feet.		lbs.
Simple Engines.	MONARCH ...	1869	25-lbs. to 30-lbs.	7470	11·8		2·79
	DEVASTATION*	1873		5652	11·64		2·928
	HERCULES ...	1869		7187	12·5		2·811
	SULTAN ...	1871		8778	11·19		3·109
	DRUID ...	1871		2038	12·6		3·001
MARENGO ...		1872 French	Compound Engines.	3535			3·04
					L.P. Cylinder	Total	
Compound Engines.	BRITON ...	1870	55-lbs. to 60-lbs.	2019	13·4	17·8	1·981
	THETIS ...	1872		2036	13·6	18·0	2·545
	THETIS ...	1873		2000			2·600
	AMETHYST ...	1873		1990	14·7	19·6	2·463
	ENCOUNTER ...	1873		2030	14·5	19·4	2·425

* Twin Screw.

Referring to the results given in the table, which are in all cases for trials at full power, it is also to be noted with regard to the trials of the simple engines, that the rate of combustion per square foot of grate was from 20 to 25 per cent. greater than in the high-pressure compound engines, and this no doubt tended to a less economical result in the simple engines.

The striking difference between the performance of the *Briton's* engines and the results obtained with the engines of her sister ships *Thetis*, *Amethyst*, and *Encounter*, having machinery made from the same patterns by the same makers was pointed out in the article in *Naval Science* for April, 1874, referred to above, and it was also shown that there were very good grounds for supposing that the accuracy of the *Briton's* low power trials could not be depended upon. With regard

to the consumption of fuel there can be no doubt that the difference between the figures registered for this ship and those calculated for her consorts is very singular. Thus, the consumption of fuel per I.H.P per hour in the *Thetis* was found to be 2·4 lbs. at 8-knot speed, while in the *Briton* at this speed it was calculated at 1·67 lbs., and at 10 knots 1·3 lbs. Assuming the figures given for her engines in the table above to be correct, however, and taking a mean of the figures for the five trials of these ships we have 2·4 lbs., the probable expenditure of fuel per I.H.P. per hour in this type of engine, while as a mean of the performances of 5 simple engines, we have 2·93 lbs.

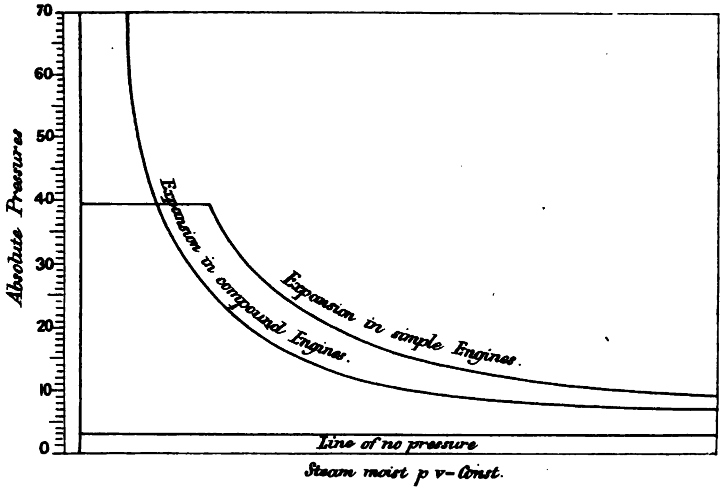
In estimating the quantity of work which can be performed per lb. of fuel by an engine working with steam at any given pressure and rate of expansion, it is practically correct to assume that the energy in the form of heat, and consequently the quantity of fuel required to produce a given weight of steam, will be the same at any pressure. The heat required per lb. of steam actually increases as the pressure increases, but at so slow a rate that the increase may be ignored in the present case. For example, Professor RANKINE calculates that the expenditure of heat required to produce a given weight of steam at the pressure of 10 atmospheres (about 147 lbs. on the square inch of absolute pressure) the feed water being at the temperature of about 100° Fahrenheit, is greater than that required to produce an equal weight at the atmospheric pressure in the proportion only of 1·04 to 1 or 26 to 25 nearly.

Also, as the total expansion in the compound engine depends upon the capacity of the low-pressure cylinder, in comparing the rate of expansion in the two types of engine, the volume swept by the low-pressure piston per I.H.P. per minute will be compared with the total volume swept per I.H.P. by the pistons of the simple engines.

DIAGRAMS SHOWING RATE OF EXPANSION
IN SIMPLE AND COMPOUND ENGINES

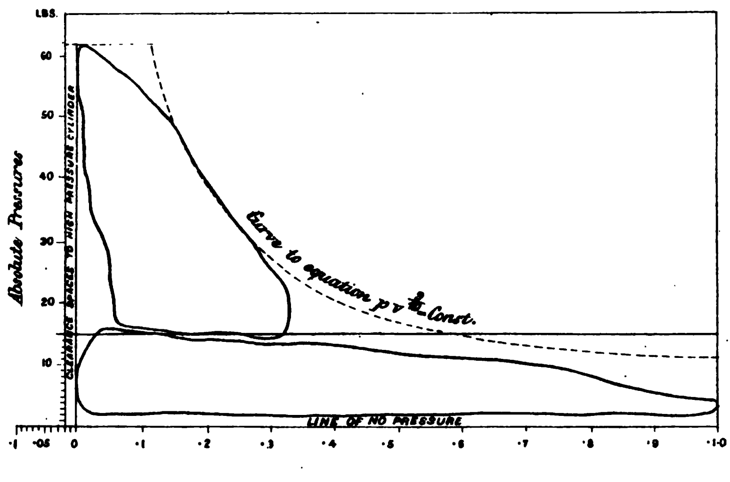
As calculated from the volume swept by the Pistons.

FIG. 1.



H. M. S. "BRITON" (*Engine A*)

FIG. 2.



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The available pressure may fairly be taken at 70 lbs absolute per square inch for the compound engine, against 40 lbs. absolute in the simple engine. Comparing then, for example, the *Monarch* with the *Thetis,* we have an effective capacity of cylinder of 11·8 cubic feet against 13·6 cubic feet, the mean effective pressures being 19·35 and 16·8 lbs. respectively. Assuming the steam to be moist and that the absolute pressure × volume is practically constant, the ratio of expansion in the compound engine will be 13·3, and in the simple engine 5, a back pressure of 3 lbs. being allowed for in each case. The weight of steam used per I.H.P. under these circumstances, in the engines, should be in the ratio of 1·31 to 2 or of ·655 to 1. A graphic illustration of the result is shown in fig 1.

If, therefore, the engines of the *Thetis* had been as efficient at the higher pressure as the *Monarch's* at the lower pressure, the consumption of fuel per I.H.P. would have been less than in the *Monarch* in the proportion of 0·655 to 1. Bearing in mind the facts in reference to the mode in which the trials were conducted it will be evident that if the mean consumption of fuel for the 5 trials of each type of engine are compared, the circumstances are not favourable to the simple engine, and instead of 2·4 lbs. of fuel being used per I.H.P. per hour it will be seen that 1·92 lbs. at most should have been used at the higher pressure and rate of expansion.

Instead of any gain having resulted from the expansion in two cylinders the cost of a horse-power has been thus apparently 25 per cent. in excess of what might fairly have been expected from the higher steam pressure and rate of expansion, presuming that one great object of separate expansion had been attained, viz.: the prevention of liquefaction at the higher grades of expansion.

One fertile cause of loss of efficiency in the engine is no

doubt that already referred to, viz.: ineffective expansion between the two cylinders, and notwithstanding the introduction of re-heaters between the cylinders, as in the case of the *Briton* and *Thetis*, and the use of various arrangements of valve gear, various dispositions of cylinders, &c., unavoidable loss from this source, and from liquefaction due to various causes, is invariably found when the diagrams are combined as in fig. 2, which shows a combined diagram for the *Briton* at full speed. The loss shown here is by no means exceptionally great.

In *Naval Science*, a pair of diagrams from the Royal Mail Steamer *Elbe* are combined in order to show this loss, and also the misleading character of a "coefficient," calculated for these diagrams by the makers of the engines, Messrs. ELDER and Co. A copy of this combined diagram is given in fig. 3, and a dia gram from a single cylinder engine working at very nearly the same pressure and rate of expansion, given in *Naval Science* for comparison, is shown in fig 4. The *Elbe's* diagrams were forwarded as specimens by Messrs. ELDER and Co., to the Committee on Designs, and they are of peculiar interest as showing the best results of about 20 years' experience in the construction of this type of engine, the firm having had also, it may be presumed, the special advantage, up to the time of his death, of the advice of Professor RANKINE, the personal friend of the late Mr. JOHN ELDER. The weight of steam apparently used in the cylinders per I.H.P., as shown by the diagrams, and other particulars are given in the table below :—

—	Saltaire Simple Engine.	Elbe Compound Engine.
I.H.P. Maximum	560	3183
,, Mean during this trial	480·4	1452·28
,, From Cards engraved	454·3	1556
Piston Speed, Feet per Minute	420	380

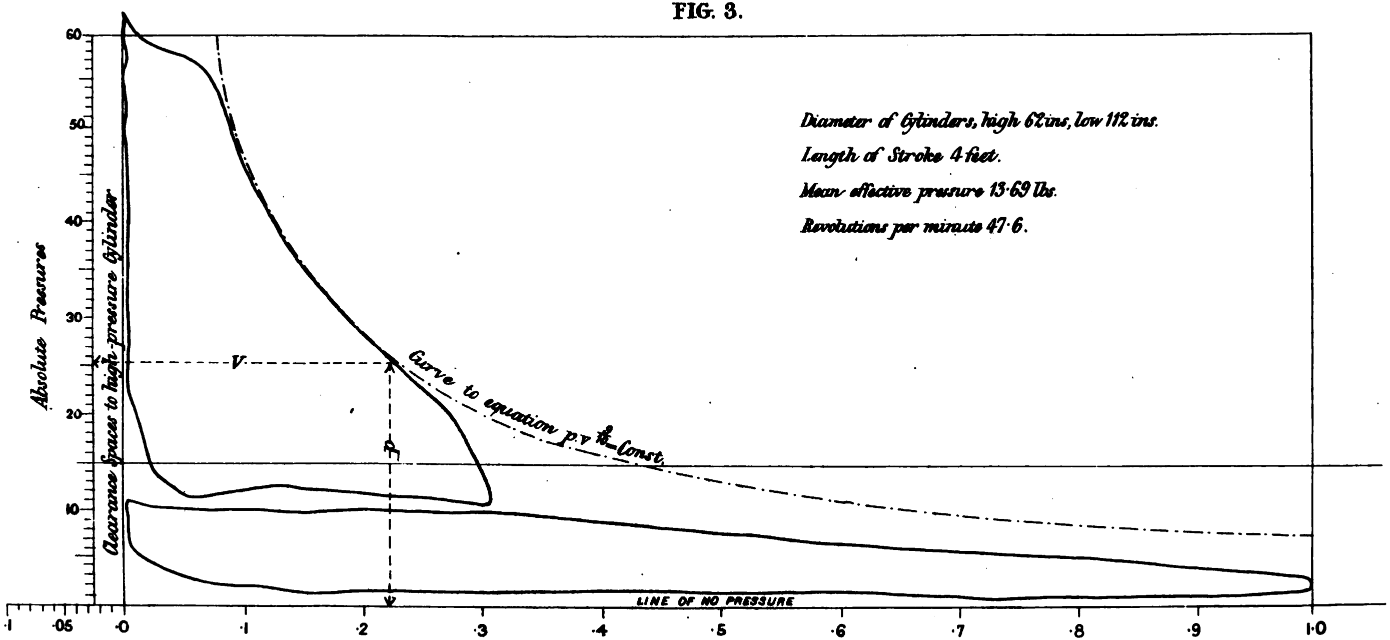
FROM "NAVAL SCIENCE"

For April 1874.

ROYAL MAIL STEAMER "ELBE".

Scale, 20 lbs.– 1 Inch.

FIG. 3.



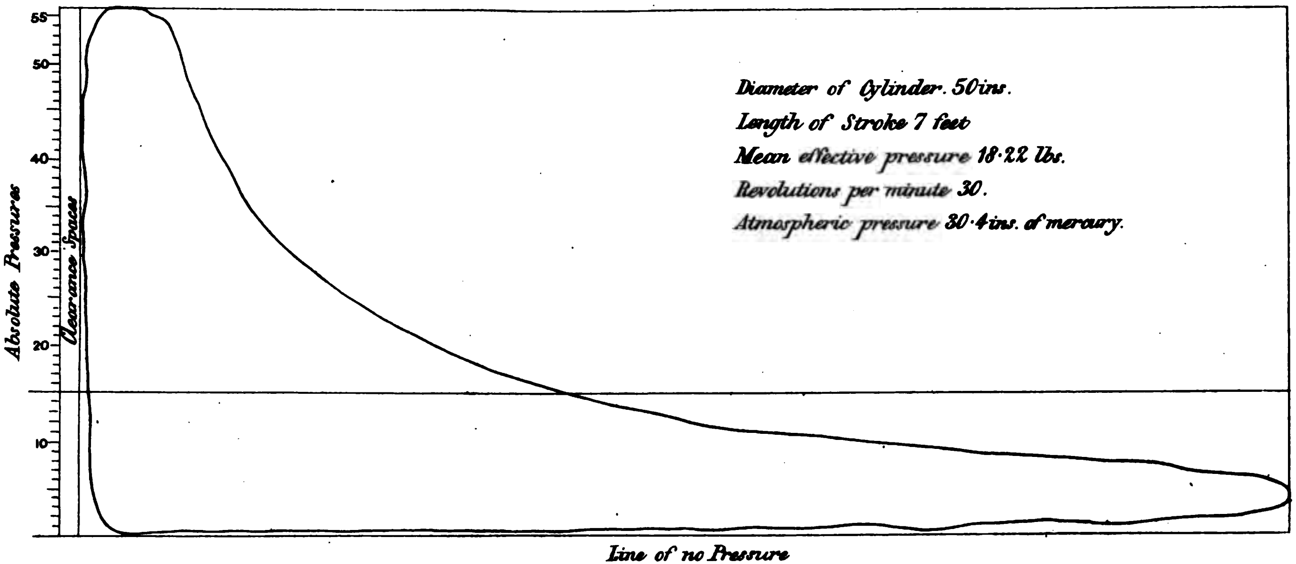
J. GRIFFIN & Cº LONDON & PORTSMOUTH.

FROM "NAVAL SCIENCE"
For April 1874.

SALTAIRE ENGINE.

Scale, 20 lbs.=1 Inch.

FIG. 4.



J. GRIFFIN & Co LONDON & PORTSMOUTH

—	Saltaire Simple Engine.	Elbe Compound Engine.
Vol. swept by Pistons per I.H.P. per min. C. Feet	12·61	22·5
Boiler Pressure —lbs. per square inch	40	45
Limits of Temperature ... ... Fah.	287° & 100°	292·7° & 100°
(*a*) Least possible Weight of Steam required per I.H.P. per hour, lbs	9·33	9·11
(*b*) Weight of Steam used in cylinders per I.H.P. as shown on Cards ... ... lbs. per hour	12·34	14·4
$\frac{a}{b}$	·756	·632
Description of Boiler	Galloway Tube	Marine' Tubular.
Water Evaporated per lb. of Fuel per hour from Temperature of 100°	lbs. 6·97	Not Ascertained.
Description of Coal used	Ordinary Yorkshire.	Nixon's Navigation.
Coal used per I.H.P. per hour, as stated... ...	2·33	2·17
Ditto calculated for evaporation of 10lbs. water per lb. of fuel	1·7	—
"Coefficient."	2·85	2·343

Naval Science says, with reference to the ELBE'S diagrams: "A mode of calculating a coefficient from indicator dia-"grams, in use by Messrs. ELDER and other firms, will be "familiar to many of our engineering readers. It is found by "dividing the mean effective pressure, referred to the low-"pressure cylinder, by the terminal absolute pressure. A "'coefficient' of 2·956 thus obtained is given by Messrs. ELDER "for the ELBE'S engines. It is calculated from the two pairs "of diagrams forwarded to the Committee, and we have "engraved the pair, giving the highest 'coefficient.' The "absurdly misleading character of a coefficient calculated in "this way in the case of the 'ELBE' will be evident at once on "examination of the combined diagram for that ship. The "mean effective pressure of the pair of diagrams, referred to "the large cylinder, is here 13·69, and this divided by the

"absolute terminal pressure in the large cylinder gives 3·004
"for the coefficient. We will now suppose the quantity of
"steam v contained in the cylinder and clearance spaces to be
"expanded in a single cylinder, and to follow the expansion
"curve of the SALTAIRE and ELSWICK engines—to continue, in
"fact, as it has begun, in the high-pressure cylinder. We
"should have here a mean effective pressure of 18·9 lbs., and a
"terminal absolute pressure of 7 lbs. The new coefficient
"would then be 2·700. Here, therefore, although there would
"be about 27 per cent. less work performed by the steam when
"expanded in two cylinders, yet the 'coefficient' would
"actually be 10 per cent. higher than for a single cylinder!
"By using the highest value of $(p\,v) - (p'v')$, found throughout
"the complete stroke, for a divisor in lieu of the terminal pres-
"sure, a more trustworthy coefficient may be obtained; $p'v'$
"being the pressure and volume of the steam compressed in
"the clearance spaces. The 'coefficients' tabulated above have
"been calculated in this way."

The inaccuracy of the coefficients given for their compound engines by MESSRS. ELDER and other engineers was first pointed out some time ago by MR. J. MCFARLANE GRAY, of the Marine department of the Board of Trade in some correspondence in *Engineering*, and if the relative efficiency of the engines were to be determined from coefficients calculated from the diagrams, there could be little doubt as to the result being in favour of the simple engine. As is well known, however, the diagram cannot be trusted in this way. With steam dried or superheated, by wire-drawing or otherwise, the weight of steam actually used will be less in some cases than shown by the diagrams even in unjacketed cylinders, while on the other hand with saturated steam the weight will exceed that shown by the diagram to an extent largely depending upon the quantity of moisture originally contained in the steam and

independently of the effect of the clothing or jacketing of the cylinders and the velocity of the piston, which again affect the result.

In one respect the engine at SALTAIRE compared in *Naval Science* with the "ELBE'S" and "BRITON'S" engines had an advantage in length of stroke which is difficult of attainment in marine engines, and more especially in ships of war, except in the case of the later iron-clads, having great beam; but making due allowance for the gain from this source in the reduction of the ratio of clearance spaces and in the possibly increased efficiency of the jacketing, (the engines are both completely jacketed,) it is probable that even then the efficiency of the steam would be greater in the simple engine in this case, judging from an examination of the diagrams and other particulars. There is but little evidence of liquefaction in the SALTAIRE diagram, the fall of pressure at the beginning of the stroke and the great rise towards the end which is most marked in diagrams from unjacketed cylinders working expansively, being practically absent; the equation to the curve is $p\,v^{\frac{9}{10}} = \text{const.}$, the effect of the clearances being taken into account in determining the index.

Looking at the great difference in the total surface jacketed, there can be no doubt that the quantity of steam used in the jackets of the compound engine must have very considerably exceeded that condensed in the jacket of the SALTAIRE engine per H.P. developed, but there remains the supposition that the loss by leakage past the pistons and valves might possibly have been greatest in the simple engine. As in the case of liquefaction, the evidence of the diagram is here no safe guide and one of the strong points urged in favour of the compound engine is, that the loss from leakage cannot be so great as in the simple engine under ordinary working

conditions, as the high-pressure steam passing the small piston merely adds to the pressure in the reservoir where it is available for work in the large cylinder. As a matter of fact, however, the work recovered in the low-pressure cylinder in this way can only be a fraction of that lost in the first cylinder, and the area for leakage is of course greatest in the compound engine.

The *Elbe's* diagrams appear to be the best of those forwarded to the Committee on Designs, and, furnished by the most experienced of the compound marine engine-makers, formed a not unimportant part of that evidence which the Committee found to be "overwhelming" and "conclusive" in proving the superior economy of the compound engine. It requires no very strict analysis to show that if the diagrams prove anything at all, they prove that engines of this type by the most eminent makers could not be expected to compete successfully on equal terms with simple engines of good design, when worked at the pressures now ordinarily used at sea.

The rest of the evidence forwarded by various firms simply went to show that the most successful of the compound engines working at high-pressure were far more economical than the low-pressure simple engines formerly in use. There cannot be the slightest doubt that the evidence of this fact is sufficiently conclusive, although there can also be no doubt that the very natural wish of makers to show the results of the performance of their machinery to the best possible advantage, has tended to preclude the possibility of this type of engine being rated at its proper value until now more matured experience has shown that its merits have been exaggerated.

In a most exhaustive paper on Marine Engines by Mr. BRAMWELL, F.R.S., the eminent President of the Institution of Mechanical Engineers, read before the Members of that Institu-

tion at Liverpool in July, 1872, particulars are given of the performances during long voyages of 19 commercial ships, fitted with compound engines by various makers. The boiler pressure varied in the different vessels from 48-lbs. to 60-lbs. above the atmosphere, the consumption of fuel, as stated, varying from 1·7-lbs. to 2·8-lbs. per I.H.P. per hour, giving a mean consumption for the 19 vessels of 2·11-lbs. With the exception of two, these engines were of the same type,—but with the cylinders overhead,—as those of the *Briton, Tenedos,* &c., having one large and one small cylinder working two cranks at right angles.

The results obtained on long voyages are so liable to error from variations in the speed of the ship, from the use of coal of different qualities, from the indicated horse-power being ascertained at considerable intervals only, and from other causes, that but little reliance can be placed upon the figures thus obtained if anything like strict accuracy be required in determining the relative economy of machinery of different types, when working under similar conditions. It would, however, be impossible to find 19 ships fitted with simple engines working with a boiler-pressure of between 15-lbs. and 30-lbs., whose logs would show a result anything like that quoted above, but it can hardly be supposed that men of such eminence as those representing mechanical science in the Committee on Designs would condemn the *type* of engine on such evidence as this, either the difference of the conditions under which the engines were worked being ignored, or the impossibility of working simple engines at a higher pressure being assumed.

Mr. Bramwell, who, as an engineer of great and varied experience, had studied the question under many different aspects, says in the paper above referred to: "Although the practical " carrying out of high-pressure steam and considerable expansion " on board ship is being done, as has already been stated, almost

" universally by the adoption of the compound-cylinder form of " engine, it is considered to be still an open question whether " the same end may not equally well be attained by single " cylinders working expansively, either arranged so that the " expansion cannot be tampered with, or else put into the hands " of truly intelligent men who will not do as their predecessors " used to do, namely, invariably throw the expansion out of " gear. It is to be regretted that fashions prevail in that which " ought to be guided entirely by science. viz.: the construction " of Marine Engines. At one time side-lever engines; at another, " oscillating engines; at another, steeple engines; at another, trunk " engines; and at another, double-piston-rod horizontal engines " have prevailed. This following of a fashion, no doubt, arises " in a great measure from the engineer being compelled to " gratify the wishes of his customer, rather than the dictates of " his own judgment. As an illustration of this, in the cases " already quoted of the compound cylinder land engines, made " by Hall and Wentworth, their customers were principally " corn millers; one corn miller knew that another corn miller " had ground his corn cheaply with a compound-cylinder " engine, and it would have been an up-hill task to persuade " the miller that he might grind his corn as cheaply with a " single-cylinder engine properly constructed. That which had " gone before he knew to be a fact, the proposal made to him he " treated as a speculation, and he therefore followed his neigh- " bour's lead and ordered a compound-cylinder engine. In the " same way, at the present date, a shipowner knows that a " certain ship is reported to have made a certain voyage in a " certain time with only two-thirds of the ordinary consumption " of fuel; he enquires how it was done, and finds it was done " by a compound-cylinder engine, and thereupon, and not un- " naturally, he thinks that he also will have a compound-cylinder " engine." The Committee appear to have been led, to some

extent, in the same way and to have assumed, in a measure, that the superiority of the engine was proved by its more extensive adoption.

Professor RANKINE, the greatest authority on the theory of the steam-engine who has yet written on the subject, in a paper intended for the guidance of the Committee, finds himself unable to give any clear reason for its alleged superior efficiency in the action of the steam. Thus, in comparing the performance of the simple engines of the *Octavia* and *Arethusa*, with the 6-cylinder compound-engines of the *Constance*, he accounts for the difference in the consumption of fuel, as follows: "The superior "economy of fuel as compared with *indicated power* in the "*Constance* is of course to be accounted for by a higher initial "pressure and rate of expansion than those used in the other "vessels, combined possibly with better jacketing and greater "superheating." Here the difference of the conditions is plainly admitted; but in the same paper, speaking generally of the two types of engine, the Professor says: "So far as the "theoretical action of the steam on the piston is concerned, it "is immaterial whether the expansion takes place in one "cylinder or in two or more successive cylinders. *The advan-"tage of employing the compound engine is connected with those "causes which make the actual indicated work of steam fall "short of its theoretical amount,* and also with the strength "of the engine and its framing, the steadiness of its action, and "the friction of its mechanism." Nothing could well be more vague than the passage in italics, and to the careful investigator, the search after the overwhelming and conclusive evidence referred to in the recommendation of the Committee, is most perplexing. There is widely admitted to be an almost entire absence of anything like exact information on the subject, even at the present date, and such evidence as is available can hardly be said to show "conclusively" that any advantage of

practical importance can really be gained by expanding in separate cylinders at present pressures.

One of the principal difficulties met with in using steam of a pressure of 50 or 60-lbs. above the atmosphere, in a simple engine, is that of providing efficient valve gear capable of cutting off the steam at a sufficiently early portion of the stroke. The steam in the SALTAIRE engine, a copy of whose indicator diagrams has been given, is cut off by the CORLISS arrangement, and this appears to have given very economical results at sea in the case of the *Circassian,** a ship of the Allan Line, which during 16 voyages across the Atlantic, indicated from 2100 to 2300 horse-power on a consumption of coal of from 47 to 53 tons per day, the average consumption being thus under $2\frac{1}{4}$ lbs. per I.H.P. per hour. The boiler pressure here was between 50 and 60 lbs.

In the gunboat *Swinger*, the only vessel having high-pressure simple-expansive engines yet tried by the Admiralty, the steam-pressure was 60-lbs. on her full-power six hours' trial in competition with the *Goshawk*, a sister vessel, exactly the same as the *Swinger* as to hull and boilers. In this case there is an expansion-valve at the back of the main slide and the steam can be cut off up to $\frac{1}{20}$th of the stroke. The result of the competitive trials was if anything in favour of the *Swinger*. The first trial was made shortly after the Committee on Designs had finished their labours, and the results, which are now very well known for the full and low power trials are as follows:—

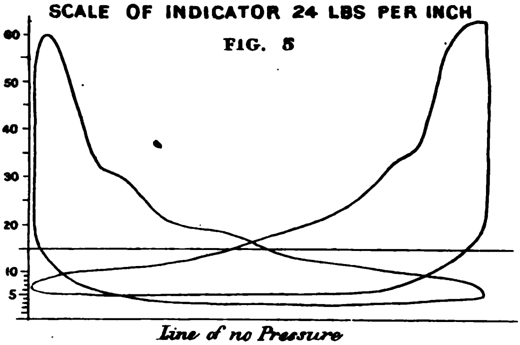
——	GOSHAWK.	SWINGER.†
Full Power.—Steam in boilers	60-lbs.	60-lbs.
I.H.P.	375	364
Coal per I.H.P. per hour ...	2·6-lbs.	2·6-lbs.
Low Power.—Steam in boilers	48-lbs.	48-lbs.
I.H.P.	78	80
Coal per I.H.P. per hour ...	2·14	2·07

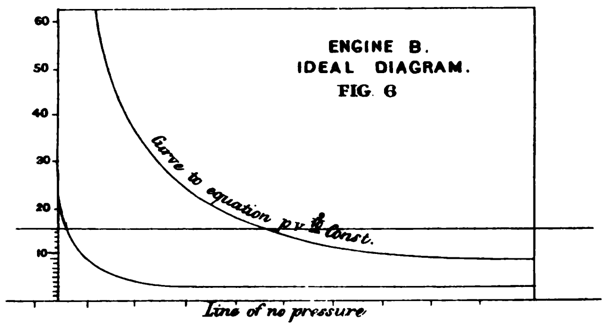
* See Appendix.

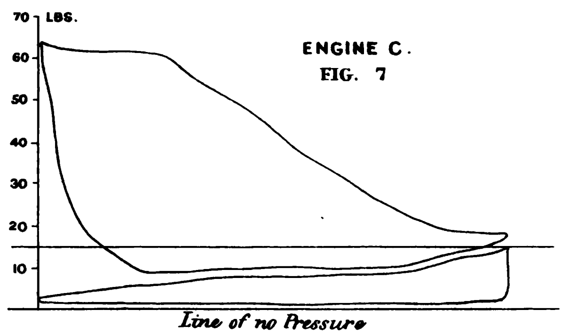
† Accurately reduced diagrams from the *Swinger* are shown in fig. 5, whilst

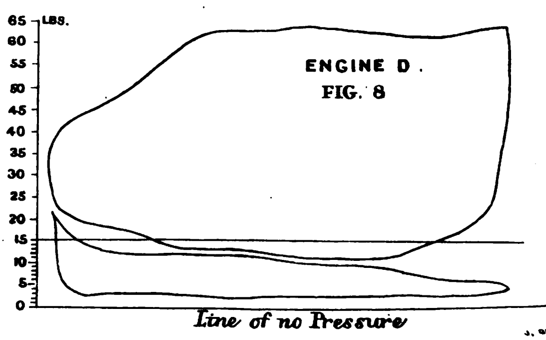
H. M. S. "SWINGER"

SCALE OF INDICATOR 24 LBS PER INCH









J. GRIFFIN & Cº LONDON

These results, so far as they can be relied upon, corroborate the conclusions which may be drawn from a comparison of the performances of the engines of the *Briton* type with those of the *Hercules*, *Sultan*, *Monarch*, &c., and it is to be noted that the *Swinger's* engines were necessarily experimental.

The principal source of loss of efficiency of the steam in the simple engine, apart from the question of liquefaction, appears to be the large capacity of the clearance spaces in proportion to the effective space at high grades of expansion, and the superior efficiency of the steam in the compound engine, presuming it to exist, must be due to no slight extent to the comparatively small waste of high-pressure steam in the clearances of the high-pressure cylinder. With the CORLISS valve gear the clearance spaces are small as compared with the slide valve arrangement as ordinarily fitted, but with due attention paid to the reduction of these spaces and to the proper adjustment of the cushioning, there appears to be no good reason to doubt that simple engines fitted with slide gear will, to say the least, compare as favourably in efficiency of the steam with the compound engine at the present, as at the former working pressure under all circumstances, if we are to judge from the results obtained on the Admiralty trials. These trials, as hitherto conducted, cannot be regarded as very trustworthy, but subsequent experience with the *Swinger's* engines at sea, so far as they have been tried, compared with the compound engines, tend to show that the comparatively good results obtained on her two separate six hour's runs were due to no mere coincidence of error in calculating the consumption of fuel.

---

below, figs. 7 and 8 are given diagrams from compound engines in use in the merchant service. Engine C, fig. 7, has two cranks placed opposite, and engine D has one crank only, the small cylinder being placed on the top of the large one. Torsion diagrams for these engines will be found further on.

The one or two engines which have been tried in the merchant service have also worked with undoubted economy, although, on the whole, they have, like the early compound engines tried in the Navy, been comparatively unsuccessful, whilst the Corliss and other well-designed early cut off engines are working by the hundred on land, with results eminently satisfactory to those who use them.

In fig. 6 is shown an ideal diagram for a simple engine with cylinders equal in capacity to the low-pressure cylinder of the *Briton*, and developing the same power as that ship. The clearance spaces are taken at $\frac{1}{20}$th of the cylinder capacity, with the expansion curve drawn to equation $pv^{\frac{9}{10}} = \text{constant}$, which appears to be approximately correct for non-superheated steam expanded in a jacketed cylinder.*

This diagram will be referred further on to two simple cylinders, together equal in capacity to the low-pressure cylinder of the *Briton*.

† This curve coincides with the expansion curves, as examined by the writer, of a number of diagrams from well jacketed Corliss engines using steam obtained from large mill boilers, under conditions favourable to the production of approximately dry saturated steam. The actual expansion curve in indicator diagrams appears invariably to rise above the hyperbola, when non-superheated steam is used, and the theoretical curves, with indices $\frac{10}{9}$ and $\frac{17}{16}$, which fall below the hyperbola, are never met with in practice apparently, except in the case possibly of super-heated steam, to which, however, they are not intended to apply.

CHAPTER V.

RELATIVE EFFICIENCY OF THE MECHANISM IN SIMPLE AND COMPOUND ENGINES.

THEORETICALLY there can be no doubt that uniformity of driving force, and a balance of turning forces tending to reduce friction on the engine-shaft bearings are most desirable things to aim at in the design of propelling machinery, but it is doubtful whether the efficiency of the mechanism is affected to any serious extent by such arrangements as it is possible to introduce in practice. Great importance was, however, attached by Professor RANKINE to a balance of turning forces, and in the report of the Committee on Designs special attention is directed to this point.

In order to show that increased efficiency could be obtained by balancing the forces, Professor RANKINE in the paper already referred to as having been submitted to the Committee, adduces the case of the *Constance*, a vessel engined by Messrs. ELDER & CO., and endeavoured to prove that the compound engines of this ship were greatly superior in efficiency of mechanism to those of the *Octavia* and *Arethusa*, ships of very similar model and size. The engines of the *Constance* had six cylinders, two high and four low-pressure; one high-pressure with its two low-pressure cylinders being placed on each side of the shaft, which had three cranks. The middle crank, acted upon by the high-pressure cylinders, was placed diametrically opposite to the two low-pressure cranks, and as the pistons moved in opposite directions, the balance of turning forces was prac-

tically perfect, while as the two sets of engines were laid in the ship, not horizontally, but at an angle of about 120° to each other, considerable uniformity of driving force was obtained.

The engines of the *Octavia*, by Messrs. Maudslay, had three cylinders with the cranks placed at angles of 120°, while those of the *Arethusa* were Messrs. Penn's well-known twin-cylinder trunk engines, with cranks at right angles.

The particulars of the competitive trials of these ships are so well known that it is scarcely necessary to give them here. Professor Rankine attached the greatest importance to the results obtained during the run to Funchal in September, 1863, and there can be no doubt that if the figures given for the performance of the engines during this trip could be strictly relied upon, the superior efficiency of mechanism of the engines of the *Constance* might almost be considered as proved. Mr. Wright, however, the Engineer-in-Chief of the Navy, who as a Marine Engineer of great experience, knew how little reliance could be placed upon the figures obtained under such conditions when minute comparisons were required to be made, pointed out in his examination before the Committee that the apparent difference in the performance of the ships in point of efficiency of mechanism might be due in no small measure to unavoidable inaccuracy in determining the indicated power. When run at the same speed as the *Octavia* on the measured mile trials there was a slight difference in favour of the *Constance*, as shown in the subjoined table, but there is a considerable difference between the performances of these two ships and that of the *Arethusa*, as will be seen here:—

—	CONSTANCE.	OCTAVIA	ARETHUSA.
Date of Trial	12th July, 1865	21st July, 1865	23rd Sept., 1865
Speed	11·373	11·54	11·704
Revolutions	56	68·5	69
Load on Safety Valve ...	32-lbs.	25-lbs.	25-lbs.
Length of Stroke ..	3-ft. 3-in	3-ft. 6-in.	3-ft. 6-in.
Indicated Horse Power	2267	2415	3165
Midship Section ...	702	701	687
Displacement	3799	3793	3709
$\frac{\text{Speed}^3 \times \text{Midship Section}}{\text{I.H.P.}}$	455·3	445·9	347·9
$\frac{\text{Speed}^3 \times \text{Displacement}^{\frac{2}{3}}}{\text{I.H.P.}}$	157·9	154·7	121·4
Number of Cylinders ...	6	3	2

These figures appear to show that the twin cylinder trunk engine with cranks at right angles was a much more wasteful propelling agent than the other two engines, of whose greater uniformity and better balance of turning forces there can be no doubt. The engines of the *Constance* had an important advantage over those of the other two vessels in that they drove a coarser screw, and this advantage is probably quite sufficient to account for the slight difference between her coefficients of performance and those of the *Octavia*, but this vessel had no such advantage over the *Arethusa*, and yet her performance was decidedly better.

The results given by the ships of the French Navy, in which the three-cylinder engines of M. DUPUY DE LÔME are exclusively used, also appear to show that a gain in the efficiency of the mechanism is obtained with an arrangement of three cylinders. With the exception of the *Gauloise* and the

Alma, the most important ships of the modern French Navy have compound engines, with the two low-pressure cylinder cranks 90° apart, the high-pressure crank being placed between these two at 135° from each. The engines of the *Alma* and the *Gauloise* have the steam admitted direct from the main steam-pipe to each of the three cylinders, and the cranks are placed at equal angles, the arrangement being in fact similar to that of the simple engines of the *Octavia*.

The reputed speed of the ships of the French Navy for a given indicated horse-power is almost invariably much higher than the speed of the ships of the British Navy of similar class. Take for example the unarmoured corvettes of the *Briton* class before referred to as having been fitted with the commercial type of high-pressure compound engine. These vessels have a displacement of 1830 tons, and with an indicated horse-power of 2100, they attain a speed of a little over 13 knots. The unarmoured corvette *Sané*, a vessel of the French Navy, intended to perform similar service to the *Briton* class has a displacement of 1755 tons, and according to the official return she attained on her trial, 13th March, 1872, a mean speed of just over 15 knots with 1980 horse-power. The coefficients are as follows:—

——	Briton.	Sané.
$\frac{\text{Midship Section} \times \text{Speed}^3}{\text{Indicated horse-power}}$	460	660
$\frac{\text{Displacement}^{\frac{2}{3}} \times \text{Speed}}{\text{Indicated horse-power}}$	160	250

The difference between the performance of the two vessels is simply enormous. The proportion of length to breadth is greater in the *Sané* than in the *Briton*, and this will no doubt

account in a measure for her better performance, but the higher speed of the French Navy generally in proportion to the power expended is very remarkable, and is held as convincing evidence by many French engineers that the traditionary superiority of form and proportion which compelled the English shipwrights during our great wars to accept the captured French ships as models is still retained in the modern state navy.

Thus, in the transactions of the *Société des Ingéneurs Civils* for 1868 the following particulars are given, from which it was attempted to be shown that the utilisation of the power indicated in the cylinders of the French ships was much greater than in the vessels of the British navy. The particulars were given by M. BELLEVILLE in reply to M. NORMAND of Hâvre, who had criticised unfavorably the French compound engines, showing their great weight per indicated horse-power developed as compared with the English simple engines by PENN, MAUDSLAY, NAPIER, &c.

M. NORMAND remarks with reference to these figures:—

" M. BELLEVILLE a insisté sur la supériorité de l'utilisation " des hélices et des carènes françaises. Suivant les moyennes " qu'il a dressées, les Anglais ne peuvent encore propulser *un* " *mètre carré de section transversale immergée* qu'à $1^m.876$ de " *vitesse par seconde pour chaque cheval indiqué*, tandis que " notre génie maritime atteindrait pour la même mesure " $2^m.176$.

" Or, le travail accompli croissant comme le cube des " vitesses ce serait une supériorité d'utilisation de 56 p. 100, " laquelle suffirait, dit-on, à compenser les deux à trois mille " chevaux qui, on le reconnaît, manquent à nos cuirassés pour " atteindre la puissance des derniers vaisseaux anglais."

Batiments Cuirassés Anglais.

Noms des Batiments.	Surface plongé du maître-couple.	Puissance developpé en chevaux de 75 kilogr	Vitesse obtenue.	Valeur de m dans la formule $v = m \sqrt[3]{\frac{F}{B^2}}$
	mq.		nœuds.	
WARRIOR ...	110·″		14·356	
BLACK PRINCE ...	111·23		13·604	
DEFENCE	95·″		11·618	
RESISTANCE ...	94·16		11·834	
VALIANT	98·″		12·633	
ROYAL OAK ...	100·40		12·53	
PRINCE CONSORT	102·″		13·12	
ROYAL ALFRED ...	101·30		13·04	
ROYAL SOVEREIGN	102·″		11·″	
ZEALOUS	105·″		12·50	
LORD WARDEN ...	104·40		13·45	
HECTOR	98·50	3256	12·360	1·965
ACHILLES.. ...	110·″	5722	14·322	1·956
CALEDONIA ...	104·″	4552	12·940	1·867
OCEAN	102·″	4244	12·896	1·898
LORD CLYDE ...	104·40	5807	13·312	1·779
PALLAS	76·″	3606	13·058	1·838
BELLEROPHON ...	99·″	5966	14·227	1·848
	Moyennes		12·939	1·878

Batiments cuirassés francais.

Noms des Batiments.	Surface plongée du maitre-couple.	Puissance développé en chevaux. de 75 kilogr.	Vitesse obtenue.	Valeur de m dans la formule $v = m \sqrt[3]{\frac{F}{B^2}}$
	mq.		nœuds.	
GLOIRE	97·81	2548	13·50	2·318
NORMANDIE ...	97·50	3253	13·30	2·107
COURONNE ...	103·77	3012	13· "	2·154
MAGENTA ...	110·"	3500	13·90	2·240
SOLFERINO ...	108·21	3631	14· "	2·213
INVINCIBLE ...	97·"	3332	13·21	2·072
PROVENCE ...	98·30	3601	13·94	2·137
FLANDRE ...	101·50	3851	14·42	2·183
HÉROÏNE	107·16	3148	13·04	2·154
MAGNANIME ...	101·06	3222	14·17	2·274
SAVOIE	99·05	3138	13·62	2·193
REVANCHE ...	99·26	3392	13·54	2·125
GUYENNE ...	98·95	3536	13·95	2·149
GAULOISE ..	99·50	3895	14·32	2·153
VALEUREUSE ..	101·57	3627	14·27	2·202
SURVEILLANTE ...	105·89	3328	13·32	2·152
	Moyennes		13·718	2·176

		Moyennes des vitesses.		Moyenne de m.
Cuirassés français	...	13·718	...	2·176
Cuirassés anglais	...	12·939	...	1·878

The comparison here instituted is of but little value. Not only are English ships of avowedly bad proportions for speed introduced, but the whole of the French ships, with the exception of the *Couronne* and the *Héroine*, are wooden ships copper bottomed. Taking, however, two sister ships, the *Swiftsure* and *Triumph*, recently added to the British Navy, which are cased with wood, copper-sheathed, and comparing them with ships of similar immersed midship section and dimensions, it will be seen that the apparent superiority of the French ships is still maintained; about one-third of the power indicated in the cylinders of the English ships being apparently wasted in overcoming resistances which seem to have no existence in the French vessels.*

Name of Ship.	Length	Breadth	Mid. Sec.	I.H.P.	Speed.	$\frac{\text{Speed}^3 \times \text{Mid. Sec.}}{\text{I.H.P.}}$
	ft. in.	ft. in.	sq. ft.		knots.	
HÉROINE, (Iron)	258 10	55 11	1153·5	3148	13·04	812·5
SAVOIE ...	258 10	55 11	1066·2	3138	13·62	858·4
GAULOISE ...	258 10	55 11	1071·0	3895	14·32	807·4
MARENGO ...	282 10	57 7½	1262·6	3535	13·335	846·9
TRIUMPH ...	280 0	55 0	1132·8	5156	14·2	629·1
SWIFTSURE ...	280 0	55 0	1141·	4913	13·75	603·8

If the vessels of the *Audacious* class, similar ships to the *Swiftsure* and *Triumph*, were compared with the French ships, the difference would be still more remarkable. These vessels are however fitted with twin screws, but, it may be remarked, of the French pattern in several cases, and one only, the *Audacious*, is cased with wood and copper-sheathed.

It certainly appears to be the fact that unless we accept the

* The displacement in tons of these vessels is as follows:—Héroine, Savoie, and Gauloise, 5,700; Marengo, 7,360; Triumph and Swiftsure, 6,633; following M. BELLEVILLE, however, a midship section coefficient is used above.

supposition that the performances of the ships of the modern French Navy are exaggerated with wonderful consistency, and of course unintentionally, we must be prepared to admit that, although the mechanical genius of this country at an early date succeeded in producing iron-built ships greatly superior in structural strength to the majority of those of the French Navy, yet in gaining the important element of high speed the French engineers of to-day have maintained the superiority which their predecessors of years ago established.

It is probable that a part of this superiority in speed for a given horse-power, presuming it to exist, is due to the use of the three- cylinder engine, but it must undoubtedly be due in the main to causes unconnected with the machinery.

The performances of the Indian troop-ships, as originally fitted with the same kind of screw, may be taken as evidence on this point. There are five of these vessels built by different firms, but to the same lines, and as will be seen below there is no

Name.	Crocodile.	Serapis.	Euphrates	Jumna.	Malabar.
Speed ... ... knots	14·003	13·378	14·718	14·656	14·570
Displacement ... tons	5633	5816	5898	6076	6161
$\frac{S^3 \times M.S.}{I.H.P.}$	531·0	520·5	518·7	537·8	534·7
$\frac{S^3 \times D^{\frac{2}{3}}}{I.H.P.}$	215·0	209·4	208·0	214·2	212·4
Cylinders, No.	2	2	2	3	2
Cylinders, Diameter ins.	96	96	$94\frac{1}{8}$	77	94
Stroke	3′ 9″	3′ 9″	4′ 6″	4′ 0″	4′ 0″
Indicated horse-power ...	4044	3698	5004	4894	4893
Screw, Diameter ...	20′ 1″	21′ 1″	21′ 0″	21′ 0″	1′ 0″
Screw, Pitch	27′ 0″	22′ 6″	26′ 0″	21′ 0″	24′ 6″

marked difference between the performance of the *Jumna*, fitted with a set of three-cylinder engines, and that of her sister ships when tried on the measured mile at full power.

Thus the coefficients for the *Jumna* are practically the same as those of the *Malabar*, the speeds being the same.

In the *Daphne* class, vessels of some 300 tons less displacement than the *Briton* class, no gain appears to have resulted from the use of the three-cylinder engine. The coefficients are as follows:—

Name.	Nymphe.	Daphne.	Vestal.
I.H.P.	2172	1927	2154
Speed—Knots...	13·066	12·48	12·814
$\frac{S^3 \times M.S.}{I.H.P.}$	449	438	437·6
$\frac{S^3 \times D^{\frac{2}{3}}}{I.H.P.}$	138	135	133·5
Number of Cylinders	3	2	3

There can be no doubt that if an advantage of much importance were due to the three-cylinder engine it would have shown itself in a marked manner in the trials of these two classes of ships.

Looking, however, at the performance of the *Octavia* and of the French ships it appears to be probable that where the number of moving parts introduced is not excessive, a better balance and greater uniformity of turning forces than can be obtained with two cranks at right angles, is conducive to economy of power; but where, as in the case of the *Constance*, the moving parts are greatly multiplied, there can be little doubt that although in one sense theoretically perfect, the loss from the enormous increase of friction of the slides, pistons, &c.,

more than counter-balances any gain which may result from the reduction of the friction of the engine-shaft, and from the possible lessening of the slip of the screw, due to want of uniformity of motion. It is notorious that in the *Constance* the application of powerful jacks was sometimes required in order to get the engines to start, and they could not be regarded as a success by any practical marine engineer.

The result of the competitive trials was, that the Admiralty of that day viewed with no favour the type of machinery represented by the too-perfect engines of the *Constance*, and the general use of the twin-cylinder simple engine, with cranks at right angles, was continued in the Navy until within the past few years. Although not theoretically perfect in one particular, these engines could at all events be generally depended upon to start when required, and the number of parts was not so great as to put the requisite mastery of their details beyond the grasp of any man of ordinary capacity who happened to be placed in charge of them.

Turning now to the practice in the commercial marine it is instructive to note that some of the most popular and successful compound engines of recent build are those in which the variation and balance of turning forces are least favourable to efficiency of the mechanism. The torsion diagrams for engines A, C, D, show plainly the forces due to the pressure of the steam during a revolution in compound engines of types now in general use. In order to render the comparison as complete as possible, actual indicator diagrams have been selected in which the initial absolute pressures practically correspond, and taking engine A as a basis, the low-pressure diagrams for C, D, have, as will be seen in the table below, been referred to cylinders of the same diameter as in engine A, the high-pressure diagrams being referred to cylinders bearing the same

ratio to this low-pressure cylinder as in the engines from which the diagrams were taken. The indicator diagrams are shown in figs. 7 and 8 for engines C and D. Engine A has two cylinders side by side, with cranks at right angles, and the diagrams are

Engine.		A.	B.	C.	D.
Diameter of Cylinder (large) ...		ins. 100¼	ins. 70⅞	ins. 100¼	ins. 100¼
" " (small) ...		57	70⅞	44⅞	44⅞
Length of Stroke		2′ 9″	2′ 9″	2′ 9″	2′ 9″
Number of Cylinders		2	2	2	2
Initial absolute pressure in lbs. per square inch	high	62	62	64·3	62·5
	low	16		15	22
Maximum strain on piston rod in tons... ...	high	53·5	105	39	99·2
	low	49·3		44	
Maximum bursting strain on cylinder cover in tons (above atmosphere)	high	53·5	82·8	34·8	33·5
	low	3·5		0·0	2·5
(*a*) Maximum turning force, tons	Reaction of moving parts neglected.	53·5	63·2	55·7	67·4
(*b*) Mean turning force, tons		42·	42·	28·9	35·8
(*b′*) Minimum turning force, tons		33·0	17·6	0	0
$\frac{a}{b}$		1·26	1·5	1·9	1·88
$\frac{a}{b'}$		$\frac{1{\cdot}62}{1}$	$\frac{3{\cdot}6}{1}$	$\frac{55{\cdot}7}{0}$	$\frac{67{\cdot}4}{0}$
Relative position of cranks ...		90° apart	90° apart	180° apart	singlecrank
Ratio of cylinder capacity ...		$\frac{3{\cdot}08}{1}$	simple engine	$\frac{5}{1}$	$\frac{5}{1}$

constructed for the engines of the *Briton*, the indicator diagrams (see fig. 2) having been taken at the full power trial of that ship.

The effect of the inertia of the moving parts is not taken into account in any of the diagrams, the strains given being ap-

ENGINE A. "BRITON" TYPE.

COMPOUND ENGINE. TWO CYLINDERS. CRANKS AT RIGHT ANGLES

FIG. 9

TURNING FORCES FOR BOTH CRANKS COMBINED FOR A COMPLETE REVOLUTION.

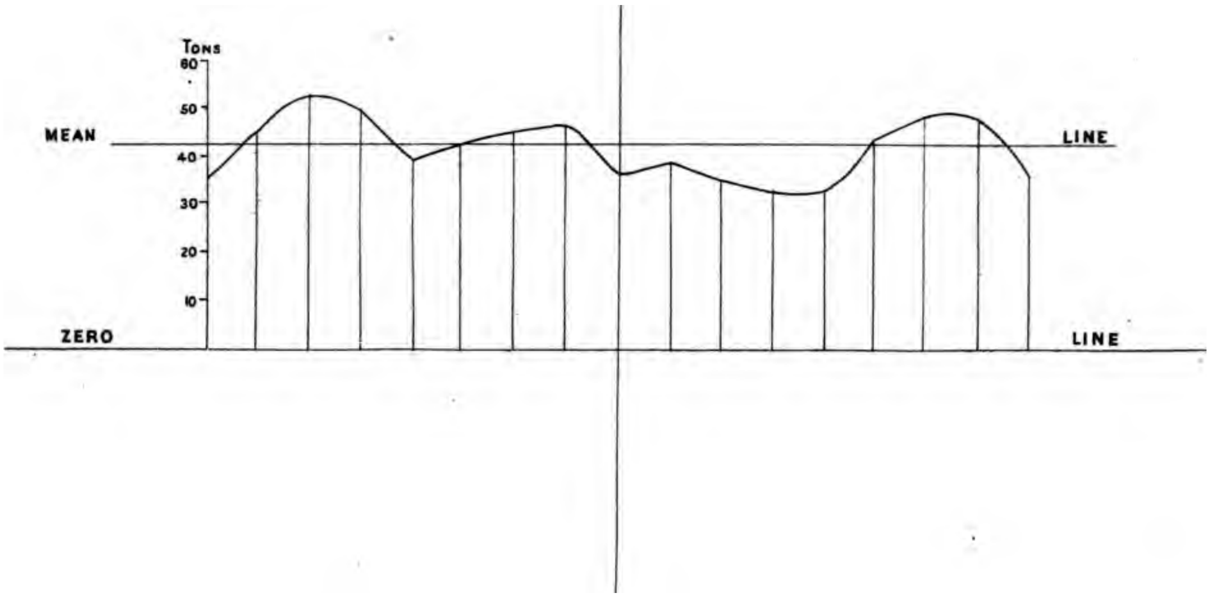
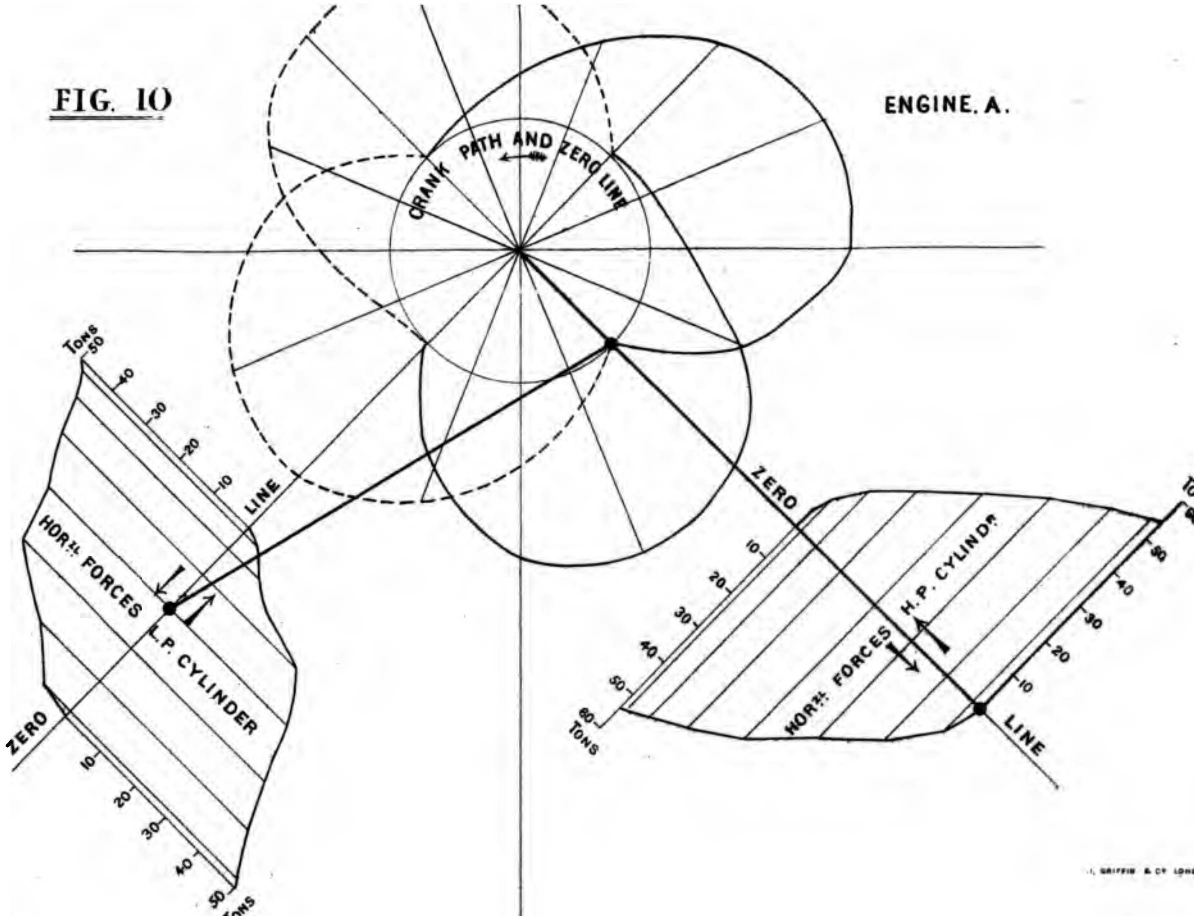


FIG. 10

ENGINE. A.



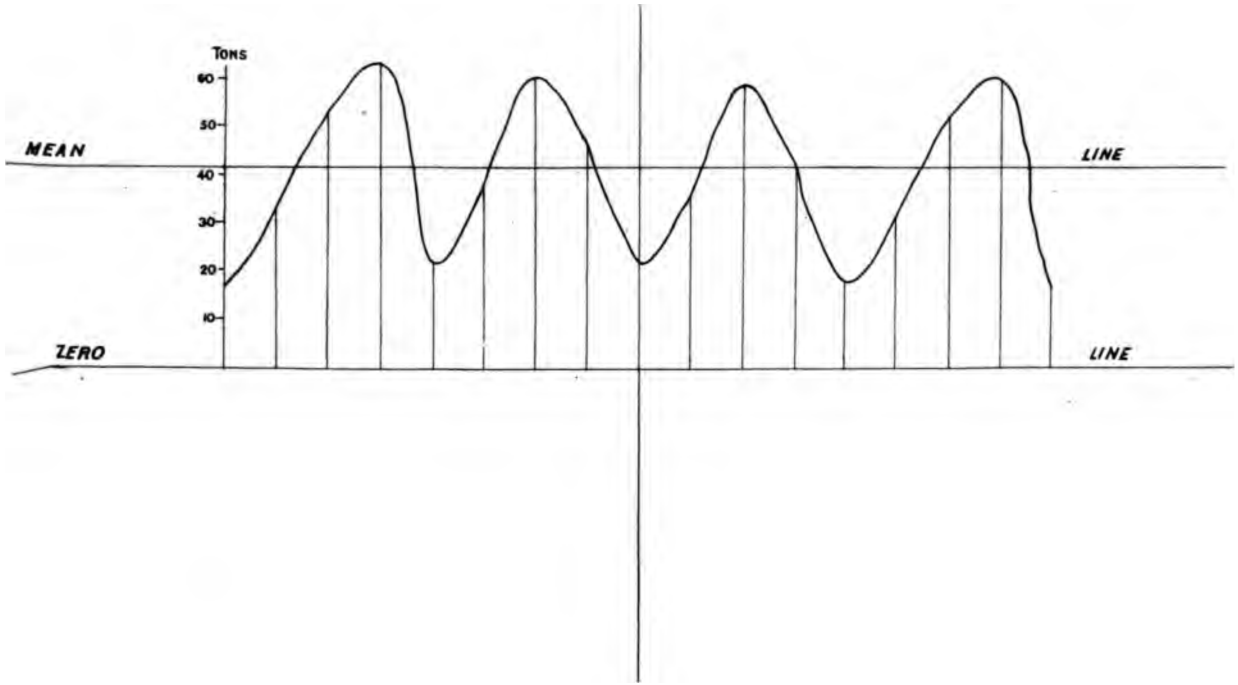
I. GRIFFIN & CO. LONDON & PORTSMOUTH.

ENGINE B. "SWINGER" TYPE

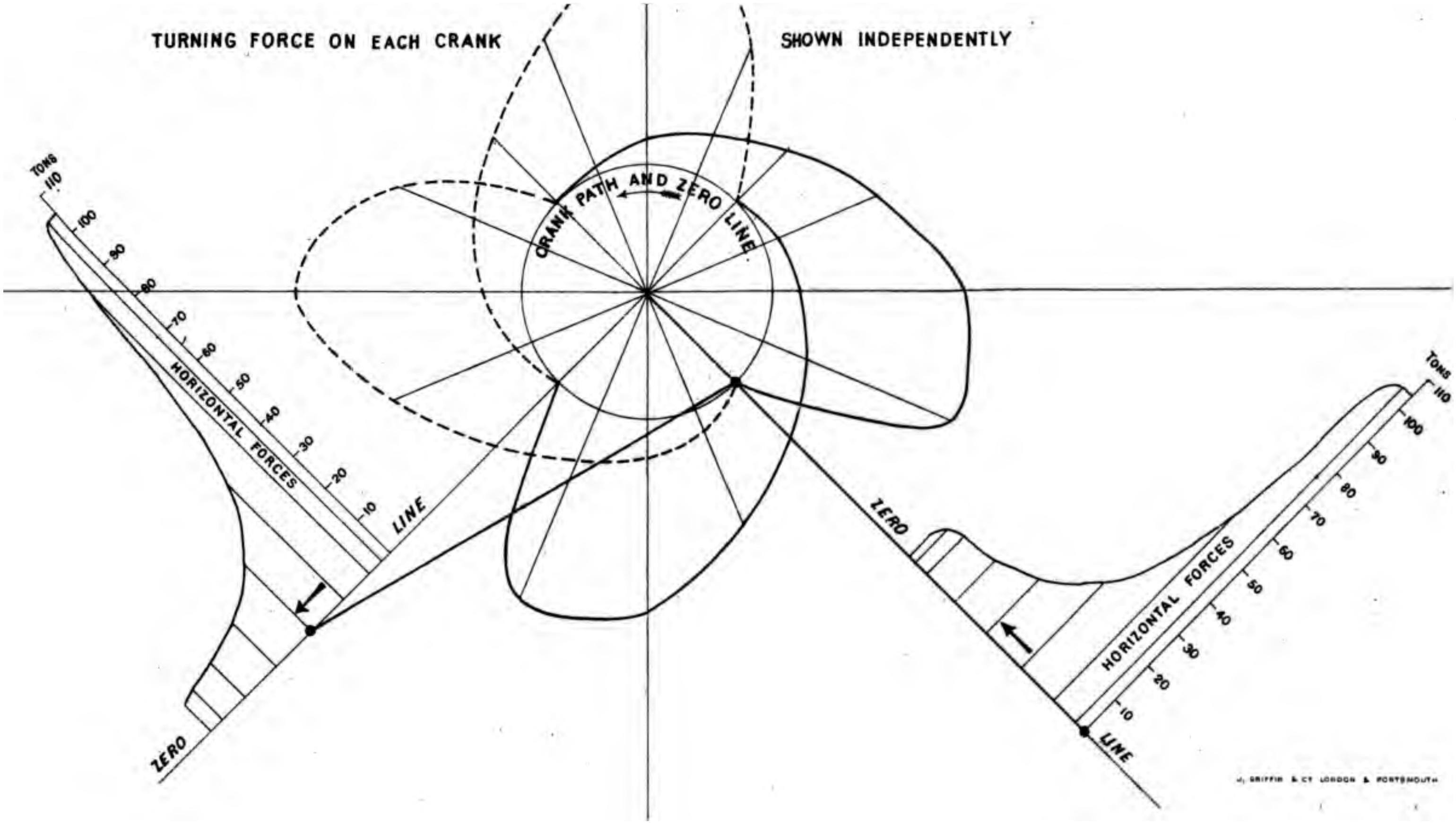
SIMPLE ENGINE, TWO CYLINDERS, CRANKS AT RIGHT ANGLES.

FIG. 11

TURNING FORCES FOR BOTH CRANKS COMBINED FOR A COMPLETE REVOLUTION.



TURNING FORCE ON EACH CRANK SHOWN INDEPENDENTLY



J. GRIFFIN & Cº LONDON & PORTSMOUTH

ENGINE C. COMMERCIAL ENGINE.

TWO CYLINDERS, COMPOUND. CRANKS AT 180°

FIG. 13

TURNING FORCES FOR BOTH CRANKS COMBINED FOR A COMPLETE REVOLUTION.

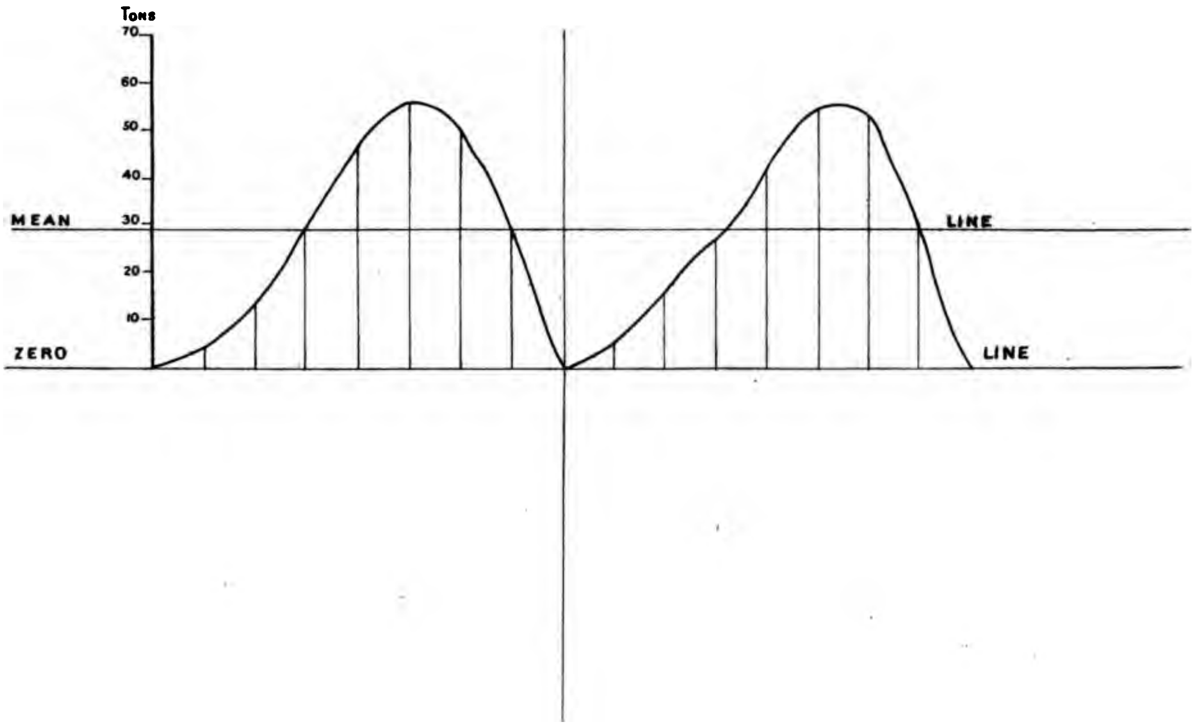
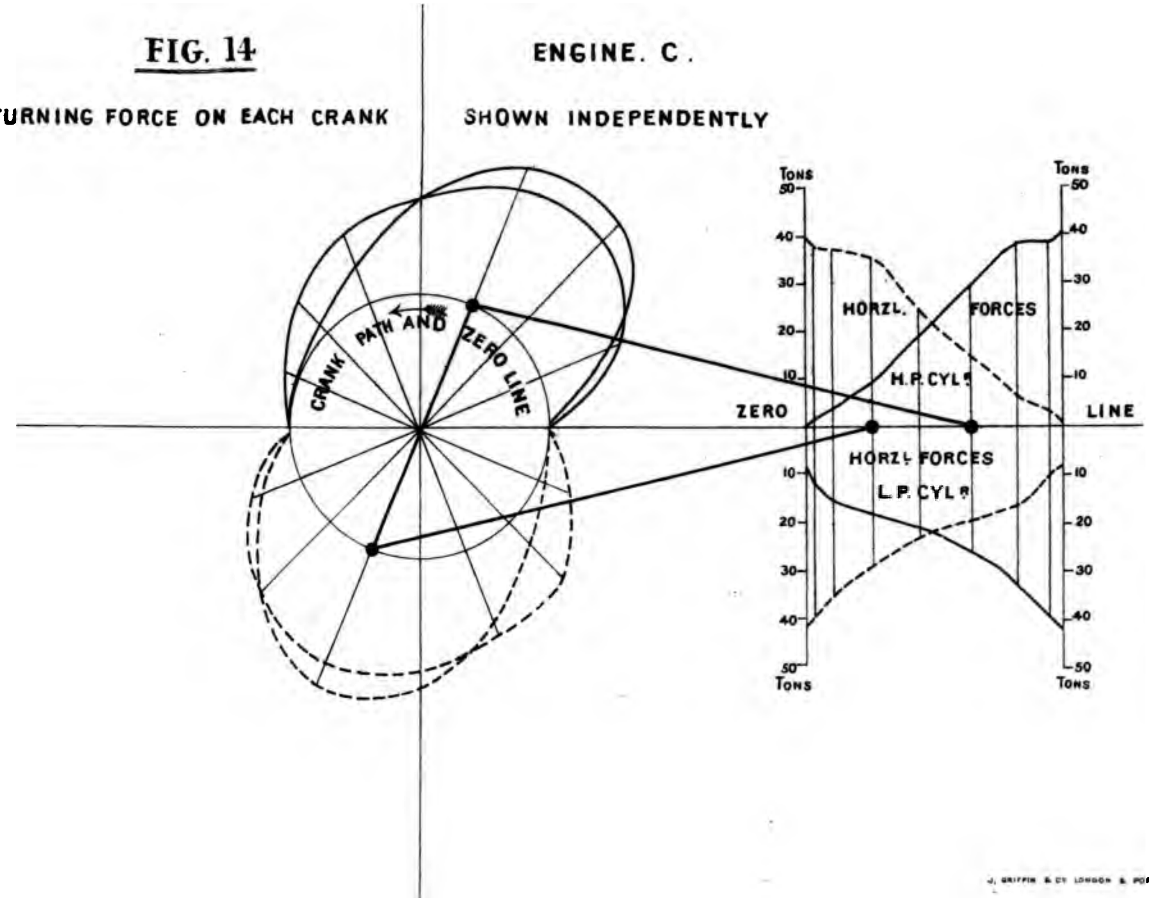


FIG. 14

ENGINE. C.

TURNING FORCE ON EACH CRANK SHOWN INDEPENDENTLY



J. GRIFFIN & CO. LONDON & PORTSMOUTH.

ENGINE D. COMMERCIAL ENGINE.

TWO CYLINDERS, COMPOUND WITH ONE CRANK.

FIG. 15

TURNING FORCE FOR A COMPLETE REVOLUTION.

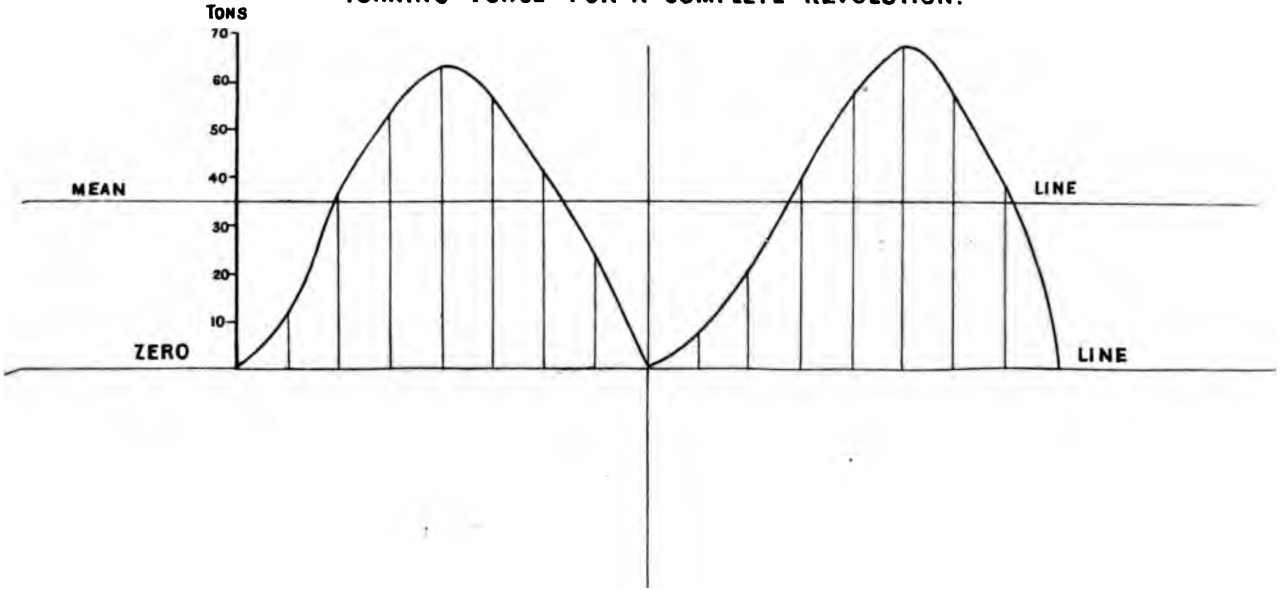
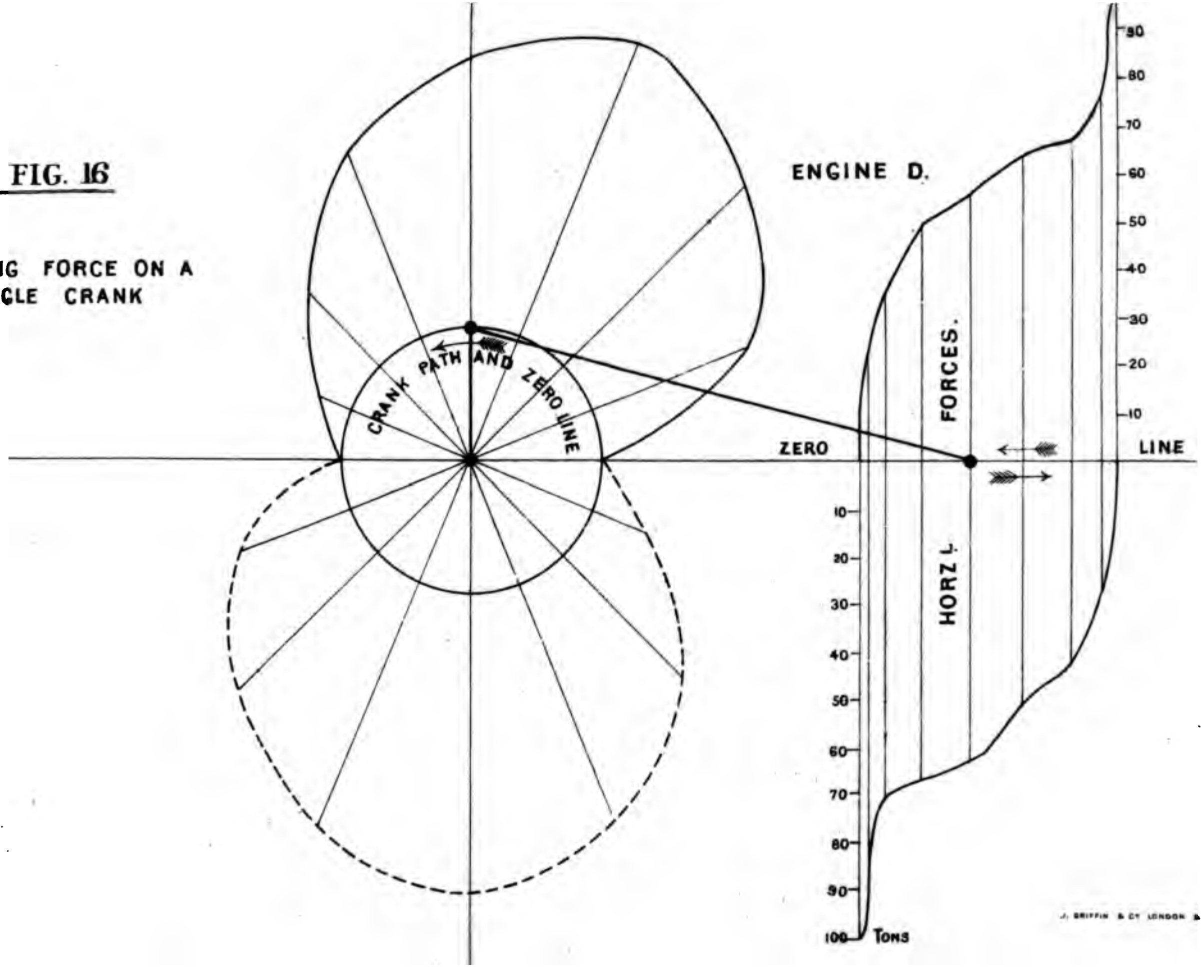


FIG. 16

TURNING FORCE ON A SINGLE CRANK



J. GRIFFIN & CO. LONDON & PORTSMOUTH.

proximately those to which the engines would be subject when moving slowly, under which condition the mechanism is as a rule most strained. For engines, whether compound or simple, in which the pitch of the screw and weight of moving parts are the same, the effect of the re-action of the moving weights is similar and tends in all cases, where the steam is used expansively, to equalise the horizontal force transmitted through the piston-rod.

Engine C has two cylinders side by side, with the cranks placed opposite each other. The return stroke of the one engine is here performed at the same time as the forward stroke of the other, and, as will be be seen from the diagram, the turning forces approximately balance each other for every position of the crank, the pressure being relieved from the shaft bearings.

Engines of type C fitted by Messrs. HUMPHRYS & Co., and other engineers, have given most satisfactory results. Owing to the cut-off being early in the indicator diagrams given for this type of engine, the mean turning force is very much less than in the other engines and the variation in the turning force is much less than it would be if the same power were being developed as in the *Briton*. But it will be seen that even as shown the turning force varies twice from 0 to 55 tons during a single revolution. Beyond casting the turning-wheel heavier than usual so as to make it act as a fly-wheel, nothing is required to counteract whatever evil effects may be due to this variation.

In this engine, however, the approximate balance of turning forces to which Professor RANKINE attached so much importance, exists, and must no doubt conduce to some extent to economy of power and fuel, but in engine D another extremely successful type of engine, not only is the variation of

the driving force just as great as in engine C, but the whole of the turning force is unbalanced and is transmitted to the bearings, a single crank only being provided. There are two cylinders in this type of engine, one at the back of the other, and as will be seen, the action, so far as turning force is concerned, is similar to that of a single-cylinder engine.

Engines of this kind appear to have been first introduced by MR. ALFRED HOLT, and, made by Messrs. MAUDSLAY and other first-class firms they have been very successful and are likely to become extensively adopted. A fly-wheel is fitted to this engine as in type C, and in both cases a small engine is provided to turn the engine over the centre in the event of its hanging up at starting.

The torsion diagram for engine B is constructed from the ideal indicator diagram fig 6, made to show the expansion in a simple twin-cylinder engine having cylinders equal in capacity to the low pressure cylinder of the *Briton*. It will be seen at once from the table and diagrams that the whole of the mechanism is strained to a far greater degree than in the *Briton's* compound engines, but that there is a decided advantage over engines D and C in regularity of turning force, while the unbalanced thrust upon the bearings is never equal to that in D.

So far as the efficiency of the mechanism is affected by variation and balance of the driving forces, engine B is very similarly situated to the engines of the magnificent steamers of the White Star Line built by Messrs. HARLAND and WOLFF of Belfast, and engined by MAUDSLAY and other engineers. These steamers are driven by two pairs of engines of the type D, the two cranks being placed at right angles. They probably average the highest speed of any of the ships of the great trans-Atlantic lines, making their passages with the utmost regularity

in all weathers; the engines doing as much work as could ever be required from those of a ship of war, under any circumstances, in the same time.

As might have been expected from experience with other engines, in the instances in which the simple engine has been worked expansively at 60-lbs. pressure at sea, there has been no evidence of loss of efficiency from the greater irregularity of turning force. Accurate results of experiments with commercial ships fitted with simple engines are not known to the writer, but the experiments with the gun-boats *Swinger* and *Goshawk* show that a pair of simple engines with cranks at right angles will drive a ship at the same speed for the same indicated power, as a compound engine worked at the same pressure and rate of expansion, and having cranks in the same position.

When on their full power trial these two vessels ran side by side for the six hours, the horse-power indicated being practically the same in both boats*, and on their full power trials at the measured mile when tried at the same draught, and with screws of similar construction, the results were slightly in favour of the simple engines of the *Swinger*, the coefficients being as follows:—

——	SWINGER.	GOSHAWK.
$\frac{\text{Speed}^3 \times \text{Midship Section.}}{\text{Indicated Horse-power.}}$	413·5	393·1
$\frac{\text{Speed}^3 \times \text{Displacement}^{\frac{2}{3}}}{\text{Indicated Horse-power.}}$	127·3	121·0

It will be seen that with three cylinders the simple engine giving an indicator diagram, like fig. 6, would be in a much

*The horse-power was slightly less in the *Swinger* as will be seen on page 24. The displacement coefficients for this run are—*Swinger* 152, *Goshawk* 148.

better position as to balance and uniformity of turning forces than the engines of the White Star Line for example, and this arrangement would enable one cylinder to be disconnected at low speeds, or when disabled, still leaving a manageable and very well balanced engine to propel the ship.

CHAPTER VI.

RELATIVE EFFICIENCY OF THE SIMPLE AND COMPOUND ENGINES UNDER FIRE.

ABOUT one-third of the entire length of a ship of war amidships is usually taken up by the engines and boilers. In a first class ship a mark of 100 or 120 feet in length is therefore presented to an enemy, and the extent to which the safety of the ship is endangered in an engagement from injury to any part of the machinery throughout this length, is determined as a matter of course by the relative importance of the part injured, and by the extent to which the results of its failure can be readily neutralised in the excitement of an action. With the large high-pressure cylindrical and oval boilers now used it is impossible to keep the steam-pipes and the steam-chests, if fitted, at any great distance below the water-line, and where the engines are vertical we have close to the water-line a range of thin copper steam-pipes reaching the whole length of the engine and boiler rooms.

About two-thirds of the machinery space is taken up by the boilers, and these, together with the steam-pipes would, it need hardly be said, run exactly the same risk of being struck, whatever the form of engine. In view of the facility with

which heavy guns of great precision can now be made and mounted on shipboard, there can, it is to be feared, be but little doubt that notwithstanding the thickness of the armour of a few of our newest ships, the risk of the boilers or steam pipes of the majority of the ships of our fleet being injured in action would probably be as great, if not greater, than in the sea-fights of the American civil war, and as will be remembered, accidents to the steam machinery were among the most frequent causes of disaster at that time.

Thus, for example, in the fight at the mouth of the Roanoke, in May, 1864, between a Federal squadron and the Confederate ram *Albemarle*, the Federal ship *Sassacus* had successfully engaged and rammed the Confederate until a shot pierced through her bunkers and one of her boilers, filling the battery in an instant with steam, which drove the men from their guns, the ship being at once placed *hors de combat.*

In an engagement on the Mississipi with the Confederate *Arkansas*, the Federal ram *Lancaster* had one of her boilers shot through, and sank in a few minutes. Again, in the famous duel between the *Merrimac* and the first American monitor in Hampton Roads, the boiler of the Federal gunboat *Dragon*, which ventured to interfere during the fight, was burst by a shell from the *Merrimac*, the explosion resulting in the wholesale slaughter of the unfortunate crew.

The boilers of these gunboats appear to have generally worked at about 40-lbs. pressure per square inch, and in order to show the probable effect of the bursting of one of the large high-pressure boilers now used in our war ships, *Naval Science* quotes as follows an experiment recently made by the American Government, with a marine boiler having about the same capacity as one of the new high-pressure boilers :—" The official " report states that the width of the boilers experimented on

" was 12-ft. 2-in., its length 15-ft. 5-in., and its height, exclusive " of the steam-drum, was 8-ft. 6-in. The pressure was gradually " increased so as to explode the boiler. At the pressure of " 50-lbs. per square inch, some of the braces in the boiler gave " way with a loud report, and when the pressure of 53½ lbs. " was reached the boiler exploded with terrific violence. The " steam-drum and a portion of the shell attached to it, forming " a mass of about 3 tons weight, were hurled to a great height " in the air, and fell to the earth at about 450 feet from the " original position of the boiler, crushing several trees in their " fall. Two other large fragments fell at less distances, while " smaller ones were thrown much farther. Almost the whole " of the boiler was literally torn into shreds, which were " scattered far and wide, the only portion remaining where the " boiler had been being the tubes. The boiler seems to have first " yielded by the fracture of the upper row of horizontal braces. " The larger masses were all thrown in one direction—at right " angles to the side of the boiler; but the smaller fragments " were projected radially in all directions, as from a centre. " Two heavy bomb-proofs, constructed of large timber and " sand, for the protection of the other boilers, were dislodged, " and a part of the fence of the inclosure was destroyed by the " impact of the flying fragments."

If a ship were taken into action with 50-lbs. or 60-lbs. pressure per square inch above the atmosphere in her boilers, it is pretty certain than an explosion such as is here described might be expected in the event of a boiler being struck. A clean perforation of the shell of an ordinary boiler would probably, if the stays were not ruptured, in most cases merely result in a rush of steam which would scald all within immediate reach and fill the ship with a cloud of vapour to an extent depending upon the capacity of the boiler and its connection with its fellows.

The Americans, taught by experience in the *Sassacus* incident and other mishaps, adopted a simple arrangement of self-acting stop-valve which closed as soon as the pressure in a boiler became much less than in the main steam-pipe, any boiler which was struck being thus at once disconnected from the others. Had the unfortunate gunboat *Thistle* been provided with such valves there can be little doubt that the effect of the collapse of her boiler flue when on trial at Sheerness would have been far less disastrous, as the steam from one boiler only, instead of from all three, would have escaped into the stoke-hole.

In the event, however, of a boiler shell being extensively weakened by the rupture of several of the stays for example, through the impact of fragments of shot or masses of backing, a violent explosion would inevitably ensue, and even if the ship were not entirely disabled, there would be great risk of the consequent demoralisation placing her at the mercy of an enemy. The advantages of boilers built up of tubes for ships of war, was pointed out in one of the early numbers of *Naval Science*, and if a trustworthy boiler of this type were available it would undoubtedly possess an advantage over the ordinary marine boiler in localising the effect of projectiles. In the merchant ship *Propontis*, Messrs. ELDER and Co. have recently fitted a sectional boiler (ROWAN'S patent) working at 150 lbs. pressure in connection with a three-cylinder compound engine, in which the steam is expanded in succession in all three cylinders.†

The use of boilers of this kind and steam of higher pressure than 60-lbs. or 80-lbs. per square inch at sea can only be

*Valves of this kind were first described to the writer by an engineer officer of the American Navy, who had frequently had charge of machinery under fire; they have now been adopted in the Royal Navy.

†A set of boilers on ROWAN'S plan was also fitted about four years ago, in a French vessel called the *Haco*, by Messrs. SCOTT & Co. of Greenock. These boilers are still in use, and this appears to be the only case in which the sectional boiler has answered for any length of time at sea.

regarded as experimental at present, and experience with the water-tube box boilers in our own and the United States Navies has not been favourable, on the whole, to a type of boiler which is so liable to foul and so difficult to clean as are boilers of this type generally. The number of accidents which have attended the use of the HOWARD water-tube boilers and the failure of the boilers of the now well-known ship of the Guion Line, the *Montana*, are also discouraging.

The failure of these boilers could, however, be clearly traced to faulty design, and it is quite possible that before long the saving of fuel which may be expected to result from the use of high-pressure steam will be sufficient to induce shipowners to adopt sectional boilers if once the difficulties arising from corrosion at high-pressure can be overcome. A discussion of the merits or demerits of a type of boiler which has been for years, and must remain in any case for some time longer in the experimental stage, would however, be unprofitable and out of place in the present essay; the practical question for consideration being plainly with reference to the comparative merits of the two rival types of engine driven by ordinary high-pressure boilers of the kind recently adopted in our ships of war and now in general use at sea.

There cannot be a doubt that a commander, if he expected to meet an antagonist capable of easily piercing his armour, would simply court disaster if he took his ship into action with these boilers working at a pressure much above that of the atmosphere, and if we take the 24 inches of armour of the *Inflexible* as a measure of the penetrating power of guns now in course of construction, some idea may be formed of the probable result in any future naval engagement of counting for protection upon the resisting power of the 12 or 14 inches of side armour with which only a few of the rest of our ships are

protected. The chances are entirely against such a ship sustaining the fire to which she would in all probability be subjected without some part of the 100 or 120 feet amidships being penetrated in the region of the water-line, and with vertical engines fitted it would be next to an impossibility that the boilers, cylinders, and steam-pipes would remain unharmed in the event of complete, or even partial penetration of the armour and backing; while, as before pointed out, with regard to the *Inflexible* herself, it is pretty certain that by the time she is afloat she will scarcely be in a better position than her consorts.

The evident means of securing immunity from the more serious consequences which would result from injury to boilers and steam-pipes is that of working at low-pressure when under fire, and with the main steam-pipe, which a smart blow from a flogging hammer would rupture at any time, once perforated, the engines would of necessity have to be worked at a pressure at or near that of the atmosphere, while injuries to other parts would, under the most favourable circumstances, lead to this result.

The great reduction of speed which would follow the lowering of the pressure in the case of a ship propelled by the commercial type of compound engine is one of the most serious disadvantages its use entails. Owing to the greater relative dimensions of the high-pressure cylinder of the French engines, the type of compound engine introdued by M. Dupuy de Lome is not so objectionable in this respect as the high-pressure compound engine adopted into our own navy in which the ratio of the capacity of the low-pressure, to that of the high-pressure cylinder is $2\frac{1}{2}$ to 1 and upwards.

Even in the French Navy, however, this defect of the compound engine has excited attention, and *Naval Science* in order

to show the effect of the reduction of the boiler pressure with a compound engine of the *Briton* type, in which the ratio of cylinder capacity is 3 to 1, calculates from actual trials of the *Briton* that a speed of 7 knots is the greatest that could be expected, whereas, if the ship were fitted with simple engines having a total cylinder capacity slightly greater than that of the low-pressure cylinder of her present engines, a speed of nearly 12 knots could be obtained with steam of an initial pressure of 15-lbs. per square inch,—absolute—in the cylinders.

In France, at the instance of the late Admiral LABROUSSE, who, with other French officers had appreciated the danger from this source to the ships they were called upon to manœuvre, the engines of the iron-clad *Gauloise* were specially fitted to take steam into the three cylinders directly from the main steam-pipe. The vessel, whose speed and horse-power under ordinary conditions have already been given in the table of French ships, then attained a speed of 11½ knots, with the pressure of the steam in the boilers reduced to a point just above atmospheric pressure.

The superiority of a vessel, capable of steaming 11 to 12 knots over an opponent whose speed would only amount to about 7 knots under similar conditions, is obvious and requires but little comment. The Commander of a ship engined like the *Gauloise* could take his vessel into action at a speed sufficient to enable him to manœuvre to the greatest advantage, confident at the same time that his crew would not be driven from their guns and everything thrown into confusion by rushes of high-pressure steam, or worse still, by the sudden eruption of a boiler in a fragmentary state from the stoke-hole. Again, gashes of considerable size, in either boilers or steam-pipes could in many cases be easily repaired without the way of the ship being sensibly diminished, and the

disconnection of seriously injured parts could frequently be accomplished without difficulty.

The smaller the high-pressure cylinder of the compound engine, the greater, as a matter of course, would be the loss of speed consequent on the reduction of the boiler pressure, but the Commander of a ship having engines of this type would, under the most favourable circumstances, find himself at a serious disadvantage if he had to cope with a vessel equal in other respects to his own, but fitted with simple expansive engines. There would be in the first place the injurious moral effect upon the engineers, stokers, and the crew generally, if the vessel were taken under fire with a steam pressure* high enough to enable the ship to be manœuvred as effectively as her antagonist, and with the first serious injury to steam-pipe or boilers, would probably come demoralisation of the crew, and certainly loss of speed of the ship. Even if a violent explosion were fortunately avoided, the rush of steam would drive the men from the compartment in which the steam would be liberated and perhaps from the guns, whilst if the main steam-pipe were cut at any point over the length of from 60 to 80 feet nearest the engines, the machinery would be stopped altogether until the injury had been repaired; and what would be the chances of a rapid repair being effected in a compartment full of steam? Unless happily protected by a friend, the only course open to the compound high-pressure vessel's Commander, under such circumstances, would be either to strike his flag, or, using his available guns to the best advantage, wait for the *coup de grace* which would in all probability be delivered by his simple low-pressure antagonist, the moment the loss of motive power had been discovered.

But the reduction of the speed at low-pressure, and its

* About 50 lbs. absolute in engines of the *Briton* class for example, where the ratio of cylinders is 3 to 1.

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attendant evils, are, unfortunately, not the only weak points of the commercial compound engine. Where the cylinders are horizontal, in both cases, the difference between the relative chances of the two types of engine living intact through an action might probably be, under many circumstances, of no serious moment. Even here, however, although from the intimate connection of the cylinders there is in any case always a strong probability that if one cylinder be struck the other will also be injured by the same shot, yet the compound engine labours under the serious disadvantage that injury to one cylinder *necessarily* disables the engine altogether.

The space taken up by the cylinders in both engines is small as compared to that occupied by the boilers and traversed by the steam-pipes, but the space taken up by the compound engine is greater than in the simple to at least the extent due to the high-pressure cylinder, and when it is considered that for a compound engine of what is a medium size for a ship of war, at least 3 cylinders are required, covering a space of from 30 to 35 feet of the length of the ship, it will be seen that the probabilites of some part of the three cylinders and their fittings being struck by masses of backing, &c., are not remote even in a horizontal engine. In an engine with overhead cylinders the weak point is almost directly exposed to fire.

Whether the high or the low pressure cylinder or fittings be injured the immediate effect is the same—total disablement. Objections to its use on this score in the commercial marine have frequently been urged, and there are no doubt some circumstances in which a merchant ship might be placed where the temporary loss of the propelling power might be attended by serious danger. These circumstances are rare, however, as a ship can usually lie to until arrangements can be made to work the ship with the uninjured cylinder. Examples of this kind

are familiar to engineers who have had much experience with compound engines.

The case of the *Spain* quoted by Mr. BRAMWELL in the paper before referred to may be instanced. This ship is one of the largest class of ocean steamers running across the Atlantic, and has compound engines, developing over 3000 horse-power. The engines are vertical, but of the same type as those recently adopted in the Navy, having two cylinders with cranks at right angles; the cylinders are 60 and 106 inches in diameter.

An accident occurred during the run home across the Atlantic by the breaking of the low-pressure piston, and the only way in which the ship could be got under weigh again was by disconnecting the disabled cylinder from the crank-shaft in the first place, and then the slide-valve of the low-pressure cylinder was taken out so as to give a clear passage for the steam from the high-pressure cylinder to the condenser. If the high-pressure cylinder had been the disabled one the same operation would have had to be performed, the high-pressure slide being required to be removed in this case to allow the steam to pass from the main steam-pipe to the low-pressure cylinder. The time required to get the ship under weigh in such circumstances would, it need hardly be said, be a matter of hours, while if the injury consisted in the smashing of a cylinder, one of the likeliest things to happen in action, the engines could not be started even by this roundabout process.

On the other hand, while the bending even of the valve-spindle of one compound cylinder would stop the engine entirely until a new rod were shipped, the disconnection of a disabled independent cylinder could be readily accomplished and the uninjured cylinder made use of. It is quite true that there would certainly be circumstances where even the delay necessary for disconnection of a simple cylinder would be fatal

in a ship driven by a single screw, and with two cylinders only fitted there would also be considerable difficulty in keeping the ship under way with the one uninjured cylinder. Three cylinders are, however, as already pointed out, required for compound engines of medium size; and three simple cylinders would in any case take up less space for the same power, while so long as two remained intact the ship could be easily handled.

There are also many accidents, such for example as the breaking of a cylinder cover, or slide cover, or even of a cylinder itself, in which the simple engine might be kept going by merely shutting off the steam from the injured cylinder, the moving gear being dragged for the time being by the other cylinders; whereas, a like accident to any one of the three compound cylinders would disable the engine completely.*

It would, however, be an interminable task to speculate upon all the possibilities of accident to an engine of either type under fire, and it is not necessary to attempt to do so. It is plainly the fact that a Commander having simple expansive engines with ordinary cylinder capacity, could manœuvre his ship at sufficient speed on a *vacuum* if necessary; that if an accident to boilers, steam-pipes, or cylinders then occurred, his engineers would not be scalded nor suffocated by a rush of high-pressure steam in endeavouring to discover the injured part and to repair or disconnect it, neither would the men at the guns be hampered and demoralised by volumes of vapour and a crowd of panic-stricken stokers from below, while with regard to the cylinders, the engineer's chances of keeping the engines going even in the event of their being struck would be considerable, and injury to the steam-pipes or steam space of the boilers could be, in many cases, repaired without the speed of the ship being seriously affected.

* See also report of American Engineers quoted in the Appendix, page 65.

The importance of these advantages can best be realised when it is borne in mind that at so low a speed as 7 knots it would be impossible for the ship, fitted with compound engines, to be manœuvred with sufficient rapidity to avoid being rammed by an antagonist having a speed of 11 to 12 knots, and the probable consequences of increasing the pressure to that required for this speed are evidently not encouraging. There can be little doubt that the possession of such a superior speed, combined with so much less liability to disablement of the motive power would go far towards placing a ship upon an equality with a vessel having thicker armour. In the American war, unarmoured vessels frequently held their own against the armour-clad rams, inflicting damage upon them so long as the speed could be kept up.

Mobility is, undoubtedly, the best possible protection against either ram or torpedo. In an able and interesting article by Lieutenant Charles CHABAUD-ARNAULT in the May number (1874) of the *Revue Maritime*, the difficulty of ramming a well-handled ship under steam, and the facility with which an iron-clad may be disabled if once her motive power be affected are very clearly shown: the Lieutenant says :—" Il est certain d'ailleurs, que le coup d'éperon " n'est pas facile à donner, quand le navire qui s'efforce de " l'éviter a toute là liberté de ses mouvements. Ainsi le " *Manussas* et la *Virginia* ont *detruit par le choc*, le premier " un transport échoué, l'autre une frégate au mouillage; mais " à Charleston, le *Palmetto-State* et le *Chicorah* ne parvinrent à " couler aucun bâtiment fédéral; à Mobile, le *Ténnéssée* " manqua plusieurs fois le *Hartford* et, à Lissa, l' *Affondatore* " ne fut pas plus heureux en essayant d'éperonner le *Kaiser*. " C'est que, dans toutes ces circonstances, les navires attaqués " étaient sous vapeur et manœuvrants."

" Une bonne artillerie, placée sur un navire en bois peut

" aussi, dans certains cas, mettre un navire cuirassé hors d'état " de faire agir son éperon. A VICKSBURG par exemple, nous " voyons l' *Arkansas* renoncer à fondre sur l'escadre fédérale " au mouillage, parce que les nombreux boulets qui avaient " percé sa cheminée ne lui permettaient plus de maintenir dans " ses chaudières une pression suffisante."

By connecting the low-pressure cylinder of the commercial compound engine directly to the main steam-pipe, and the high-pressure cylinder to the condenser, the objections to it can, as pointed out in *Naval Science* for April, 1874, be to some extent neutralised. Arrangements of this description have not been adopted as yet in our own Navy, nor in any case, so far as the writer is aware, and they would still further complicate an already sufficiently complex engine*; the engine would also then become a composite or duplex machine, to which the term "compound," as implying expansion in more than one cylinder, would no longer strictly apply, it being as a matter of fact a "simple" engine (although not exactly simple in its fittings) capable of being used as a compound engine.

In view of the experience already gained there appears to be no necessity for the adoption of compromises of this kind. A three-cylinder simple engine would, however, be superior to the commercial compound engine in this respect, as if actual experience at sea proved that an advantage in some unforseen way could be obtained by a compromise it could be readily altered to the "composite" form. The engine when working "compound" would then be similar to the French compound engines, which have three cylinders of equal diameter, the complication of spare gear required with the commercial compound engine being thus avoided.

The arguments here advanced for the simple engine have

* See also report of American Engineers quoted in the Appendix, page 65.

been directed in favour of its use for armoured ships, but they apply with equal force to the machinery of unarmoured vessels. In these, however, the risks run are in some respects not so great as in ships intended to fight at close quarters, and there is no doubt much to be said in favourof the view evidently held by some continental designers, that the small additional protection against modern shell fire obtained by fitting horizontal engines is not worth having in unarmoured cruizers. These vessels are built for speed and with their narrow beam it is impossible at present pressures either to get a satisfactory horizontal engine or to keep it any distance below the waterline.

* Mr. REED'S proposal to place two pairs of simple engines in vessels of this kind, one pair abaft the boiler rooms as usual, and the other between the forward and after boiler rooms, would give many advantages, not the least of which would be the power of disconnection at low speeds or when disabled, an advantage which, as pointed out on page 42, the three-cylinder simple engine also possesses. For unarmoured ships of the highest speed, engines arranged as proposed by Mr. REED, and driving large lifting screws on Mr. HARLAND'S plan as already in use in the *Britannic*, appear to offer the greatest number of advantages and to satisfy the conditions which apply to vessels of this class.

The difficulties arising from the double system of spare gear and from the great size of the low-pressure cylinder gear of the commercial compound engine are obvious, and require no comment. They have given rise to much inconvenience, even in the merchant service.

* "The machinery of ships of war."—*Naval Science*, page 325, Vol. I.

CHAPTER VII.

CONCLUSIONS.

THE conclusions which in the opinion of the writer must be drawn from a careful examination of the subject, as a whole, may be stated shortly as follows:—

First—The great aim in designing machinery for ships intended to fight under modern conditions being to obtain *maximum* security against disaster under fire, with *minimum* complexity of parts, the compound engine at its best is altogether inferior to the simple engine in this respect.

Second—The economy of the modern compound engine is due to the use of high steam-pressure.

Third—There is no insuperable difficulty in the way of working simple engines at the same pressure as that in use at present with the compound engine at sea. Equal economy might then fairly be expected with the simple engine, specially fitted, as with the compound under ordinary working conditions.

Fourth—Even if this were not the case it would still be safest to use the high-pressure simple expansive engine, under the present system of ship and boiler construction, in use in this country.

Fifth—All available evidence goes to show that it is impossible that the compound engine can be to any serious extent superior to the rival engine at present pressures, in point of economy.

Questions of relative weight and first cost have not been entered upon. The simple engine would, however, in any case, be less costly, and at 60lbs. pressure would certainly not exceed in weight the compound engine at present in use, presuming it to be made with a cylinder capacity about equal to the low-pressure cylinder of the compound engine. Judging from the weight of engines actually made, the probability is that simple engines could be designed on less metal than the rival engine. That this might be expected will be evident when the extra weight of the spare gear and high-pressure cylinder of the compound engine is remembered; and also that as in the commercial marine, in order to provide against accidents the engine should be made to stand a pressure of some 20lbs. above the atmosphere on the low-pressure piston the shafting also being made of adequate strength.

If the figures given for the French ships can be depended upon it is evident that a change of form in our own war ships would effect a greater economy of power, and therefore of fuel, than has resulted from the adoption of the commercial compound engine in lieu of the simple engine working at 30lbs. Upon this question much light is being thrown by Mr. Froude whose investigations the French engineers appear to be watching with interest, although, judging from the reputed performances of their ships, an advance upon the perfection already attained seems scarcely practicable.

It is no doubt probable that the use of the three-cylinder engine has assisted in gaining a higher efficiency of mechanism in the French ships, and this form of the simple engine specially fitted to facilitate ready disconnection at low speeds or under fire, appears to offer the greatest number of advantages. It would be applicable to the majority of fighting ships.

Apart from provision against disablement obtained with a three-cylinder simple engine of this kind, the disconnection of a part of the cylinder capacity appears to be the only effective way of preventing the enormous waste of steam which takes place in engines of either type at low speeds. When the full capacity of the cylinders is used, experience shews that the engines are simply turned into condensers and it is only by extensive wire drawing that the evil can be to some extent mitigated in cylinders of the capacity which under present conditions must be provided.

The solution of the question of boiler corrosion at high pressures at sea would remove the principal difficulty in the way of largely reducing the cylinder capacity; and the introduction of forced draught combined with the tubulous or locomotive boiler would lead to a large reduction of the space and weight required for the boilers. Forced draught would also enable much smaller funnels and uptakes to be used, and in this way Admiral ELLIOTT'S proposition to protect the machinery by an armoured deck placed some 6 ft. under the water-line might probably be rendered practicable. Something like efficient protection for the machinery from attack *above* water could then be depended upon. Against attack *under* water, mobility, thus ensured, is, it is pretty evident, the best protection. Until better protection from projectiles can, however, be given than at present, accidents to the machinery under fire must be provided against in the design and arrangement of the engines and boilers themselves.

With regard to the crippling of the *Arkansas* by the injury to her funnel (quoted on page 54), it may be remarked that the use of forced draught would render such an accident practically impossible.

The sub-division of the engine and boiler rooms by a bulk-

head on the middle line of the ship, first introduced in the machinery arrangements of the *Superb* and *Fury*,* the boilers, and as much as possible the engines, being kept amidships, has enormously increased the defensive power of the ship against attack by ramming, or the torpedo, but protection by extensive division in this way is limited on account of the complication involved.

With reference to the question of wear it is to be borne in mind that the compound engines which have given such apparently good results in the commercial marine have invariably been vertical, and even here the jacket is being abandoned and steel liners are being fitted in order to provide against the rapid wear of the high pressure cylinder. The fitting of vertical engines in ships intended to fight at close quarters introduces an element of danger which, in view of the little dependence that can be placed upon the protection of vertical side armour, it is most desirable to avoid, and the great beam now given to the more important iron-clads gives special facilities for the introduction of long stroke horizontal engines with high piston speed. Looking at the excellent results obtained with simple trunk engines having cast iron liners, and working with partly superheated steam at 30 to 35 lbs. pressure, there appears to be no reason to doubt that horizontal simple expansive engines fitted with steel liners and using non-superheated steam at 60-lbs. pressure would work perfectly, there being but little difference between the initial temperature of the steam in the two cases: and the wear of slides, pistons, &c., simply depends—other things being the same—upon the temperature and dryness of the steam used; the conditions of working would, as a matter of fact, be more favourable in one sense in the new type of engine, as with saturated steam lubrication would be more efficient, while as the mean tempera-

* Now the *Alexandra* and *Dreadnought.*

ture of the cylinder would be lower than that of the high pressure cylinder of the compound engine greater durability might reasonably be expected.

It can hardly be supposed that the eminent men composing the Committee on Designs would have passed so sweeping a recommendation if the whole of the facts of the case had been present to their minds. Judging from the drift of their questions the two members of it having the greatest practical knowledge of the machinery of fighting ships, Mr. LLOYD, C.B., (late Engineer-in-Chief of the Navy), and Mr. RENDEL, the well-known inventor of the *Staunch* class of gunboats, appear to have been somewhat doubtful of the inherent superiority of the compound engine, even in the face of the startling results just before obtained with the engines of the *Briton* and *Tenedos*, and in view of the reputation of the engine in the commercial marine, a service to which it is evidentally no longer advisable to look for precedents in the choice of machinery for ships intended to fight.

It is to be hoped that with the light of more perfect knowledge the question may receive further consideration. There can be no doubt of its importance at the present time. So long as the lead in the construction of fighting ships is kept in this country, the introduction of an element of weakness which would be copied in the vessels of a possible enemy, could lead to no serious danger, as we should at least be able to cope on equal terms with such vessels in the event of war, relying for success on the superior pluck and intelligence of our crews, who have never failed us yet in the assertion of that supremacy at sea on which our existence as a nation depends.

Signs have, however, not been wanting for some time that powerful foreign governments are more disposed to take the initiative than to follow our lead. It is evident

on all hands that the terribly destructive character of the engines of war which are daily being perfected, will, in any future sea-fight, entail consequences the most disastrous upon the admission of any source of inefficiency in the construction and equipment of our ships, and we cannot hope that under modern conditions of naval warfare the greater skill and bravery of our men will, as on former occasions, suffice to turn the scale in our favour in spite of any possible inferiority of the ships they may be called upon to fight in.

That the adoption of the commercial compound engine in the navy has introduced a source of serious weakness is evident; that it possesses no adequate advantage there can, it is to be feared, be little doubt. A marine engine in any case must be a delicate and complex contrivance and the difficulties in the way of preventing the fatal stoppage of the motive power in the event of injury to the machinery under fire would be great, even under the most favourable circumstances, as those who are familiar with engine-room casualties are well aware. Much may be done, however, by highly skilled and determined men, such as are to be found in the engine-rooms of every ship in the British service, to keep the machinery in motion during the very few precious minutes which will in all probability decide future actions at sea; provided that the atmosphere in which they may have to work in case of accident is such as men can breathe, and that the machinery they have to deal with is not so complicated as to preclude the possibility of their realising at a glance what may be done to neutralise the effects of injury, nor so constructed as to nullify judgment and determination alike.

APPENDIX.

Notwithstanding the comparative want of success which has attended the use of the high-pressure simple expansive engine in one or two of the very few cases in which it has been tried in the commercial marine, the views expressed in the foregoing essay as to its superiority for purposes of war under present conditions are steadily gaining ground. Unlike the early compound engines tried in the Navy the experimental simple expansive engines of the *Swinger* have continued to give results so satisfactory that the Admiralty have at length ordered two additional sets of the same power, and also two sets of 900 indicated horse-power to be constructed.

The well known firm of Messrs. John Penn & Son, have in hand for a Continental government, a set of 3-cylinder high-pressure engines, intended to work as simple expansive engines at their full power, of 4 000 horses, and as compound engines when only low power as when cruising, is required. The cylinders, like those of the French compound engines are of equal diameter, the spare gear being thus simplified and made of manageable dimensions. Each cylinder is fitted with expansion gear, and when working "compound" two of of them are fitted so as to disconnect from the main steam pipe, taking steam from the third, which is then of course disconnected from the condenser.

A compromise of this kind has been commented upon on page 54, and in the hands of Messrs. Penn the most efficient arrangement possible may be depended upon. The complication necessarily involved in such a compromise appears to have been reduced to a *minimum*, and it is expected that the alteration from one mode of working to the other will be performed in less than one minute. Whether the results will be worth the complication introduced, experience will show. Simplicity always has been considered as one great essential in the design of

every contrivance intended to be used in the rough work of war, and if any one thing is certain with regard to the mechanical appliances of our fighting ships, it is that we have arrived at such a pitch of complexity, that it is of the utmost importance further complication should be avoided wherever possible. Judging from the recent American experiments, commented upon further on, it would appear that at low powers the use of the whole of the cylinder capacity with compound expansion might be expected to be much more economical than if the steam were expanded in the three cylinders independently, but, as already stated in page 58, at the low powers at which the engines of fightings ships are ordinarily driven, the cylinders are simply turned into condensers in both types of engine, and the only effective way out of the difficulty appears to be to disconnect a part of the cylinder capacity entirely.

Mr. EMERY'S experiments with the *Bache* clearly show this. It was found here that although expansion could apparently be carried to a somewhat greater extent in the jacketed compound than in the simple jacketed engine in this case without positive loss being incurred, yet that at not very extreme measures of expansion the loss was very great in the compound engine. Thus, with a ratio of expansion of 16·85 the jacketed compound engine used 28·698 lbs. of water per effective horse-power per hour, the maximum efficiency of the steam having apparently been reached at a ratio of expansion of 5·7 when the least weight of steam used is given at 21·998 per effective horse-power.

The Americans do not appear to regard a compromise with any favour, preferring to give the simple engine a thorough trial. In an interesting report to the Secretary of the Navy, by Messrs. LORING AND BAKER, Chief-Engineers U.S. Navy, published in 1874, the trial of high-pressure compound engines with less capacity of cylinder than those of English design is recommended, and the superior economy which might be expected with the engines as compared with simple engines at 30-lbs. pressure having been referred to, it is remarked: "Whether they will fulfil the requirements of the "service in other respects as well as is done by the engines now in

" use is a question that can be determined only by experience. They " are more complex in arrangement, and the details include a greater " number of parts. At least one of the cylinders must be fitted with " a separate cut-off valve and gear. There is a greater number of " steam-joints, and hence, as well as from the higher pressures " employed, a greater liability to leakage. The action of the cylin- " ders depends each upon that of the other, and neither can be made " to act by itself without the employment of special appliances of a " complicated and normally useless character, in the absence of which " the disabling of one cylinder means the disabling of both."

These Engineers further remark :—" It is only by experience, as " we have said, that the department can test the actual value of the " improved machinery for naval purposes, and determine its value for " adoption to the exclusion of other types in the future. In the " pursuit of economy the conspicuous modification of engineering " practice is in the pressure of steam employed. There is nothing " new in the compound engine except this feature. The mere com- " bination of mechanical devices that distinguish it from engines " of the common type has never availed for the reduction of the cost " of steam power, although the attempt to compass that object by " their use has been made many times : and in our judgment the " new system should be tested by competition, with such modifica- " tions of that now in vogue as would result from the employment of " the steam-jacket, and of the high-pressure and speeds of piston, to " which its superiority in economy is chiefly due."

" A very considerable gain in economy of fuel is certain to result " from these modifications, and it is also certain that the non-com- " pound engines thus converted will be convenient of management, " simple in construction, not specially liable to derangement, and " capable of operating singly by simple disengagement in case of " injury to either."

As will be seen these opinions coincide entirely with the views expressed in the Essay.

No account of the trials of the engines above proposed has yet

reached the writer, but full particulars of an interesting series of trials with the engines of three American Revenue steamers, conducted in August last, at Boston, are reprinted at the end of this Appendix, from the Report of the Secretary of the United States Navy for 1875. Although the engines experimented on were of small size, yet there can be no doubt that the results, together with those of an equally important series of experiments with the United States Coast Survey Steamer *Bache*, leading particulars of which are reprinted further on from *Engineering* of 1st January, 1875, are most instructive.

The well-known system of trial hitherto carried out on the Admiralty six hours' runs, and on the trial trips of commercial steamers in this country, is open to many sources of error, and although the greatest care is invariably exercised in the conduct of the Admiralty trials, no doubt results have sometimes been registered which, in point of economy, were physically impossible of attainment under the conditions, while on the other hand the consumption of fuel recorded has in some cases been in excess of the actual amount.

The most exact system yet tried, upon which the efficiency of the steam in an engine can be ascertained, is undoubtedly that in which the heat rejected in proportion to the work done is determined from the weight and temperature of the injection water, and from the quantity and temperature of the water discharged from the condenser and jackets. This mode of trial is specially applicable to engines having jet condensers, but it can also be applied to surface-condensing engines, and, whether the discharged water be measured in tanks or gauged on a system frequently described in *Engineering*, in which the discharged water is passed over a "tumbling" "bay" the results, if the trial be carefully conducted, show accurately the efficiency of the steam irrespective of its initial conditions as to superheating or supersaturation. For a run at sea, however, some other system appears to be necessary, and, commenting upon the *Briton's* trials *Naval Science*, for April, 1874, proposes for the six hours' runs to ascertain by means of measuring tanks the exact quantity of condensed steam discharged from the air-pumps and steam-jackets in

engines fitted with surface condensers. With steam of 60-lbs. pressure and upwards the use of the superheater has been discontinued in the Navy, and as separators are always fitted, the probabilities are in favour of approximately dry saturated steam being supplied to the engines from well-proportioned boilers of the type now in use in the Navy. The system proposed by *Naval Science* therefore should no doubt give sufficiently accurate results in most cases, and it possesses the great merit of simplicity and of being perfectly applicable to engines during a run at sea, when the machinery can alone be worked under normal conditions. The substitution of an accurate water meter in lieu of the measuring tanks, as has already been done on land, might also be found practicable.

Particulars of a trial made at Chatham Dockyard last July are given below. In these and the American trials the weight of steam used per H.P. was in all cases found by measurement in tanks of the steam discharged from the cylinders and jackets.

Trial of Dock Pumping Engines, H.M. Dockyard, Chatham, July 13th 1874.

Diameter of cylinders	H.P. 43-ins., L.P. 75-ins.
Length of Stroke	2-ft. 9-ins.
Number of boilers	6
Number of furnaces in each boiler	2
Length of fire grates	6-ft. 6-ins.
Width of fire-grates	2-ft. 6-ins.
Load on safety-valves	55-lbs. per square inch.
Mean pressure of steam in the boilers ...	53·5-lbs. per square inch.
Mean vacuum in condenser	24·4-ins.
Weather barometer	30·02-ins.
Mean number of revolutions per minute* ...	87·6
Mean pressure in cylinders	High 23·784, Low 5·993.
Indicated horse-power	High 505, Low 387,—Total 892.
Duration of trial	3 hours 32½ minutes.
Description of coal used	FOTHERGILL'S Aberdare.

* The engines drive large centrifugal pumps, and the revolutions varied with the height of lift.

Quantity of coal used...	12320-lbs.
Quantity of coal used per I.H.P. per hour	3·74-lbs.
Water collected from hot-well	60228-lbs.
Water collected from hot-well per I.H.P per hour	18·42-lb.
Water collected from steam-jacket	1312-lbs.
Water collected from steam-jacket per I.H.P. per hour	0·401-lbs.
Water collected from steam-pipes	315-lbs.
Total quantity of water per I.H.P. per hour	18·922-lbs.
Quantity of coal burnt per square foot of fire-grate	17·8-lbs. per hour.
Velocity of piston, feet per minute	481·8
Volume swept by piston per I.H.P. per minute, L.P. cylinder	16·57 cubic feet.
Volume swept by pistons per I.H.P. per minute .. .. Total ...	22·03 cubic feet.

Standing alone, the trial of the Chatham engines is but of little importance as compared with the American trials, but it is of interest, as some measure of the accuracy of the consumption of coal of 2·4-lbs. per I.H.P. per hour taken for the engines of the *Briton* class*, the Chatham engines being of the same type—fitted vertically however—jacketed in the same way, and constructed by the same makers as the engines of this ship.† It will be seen that the consumption of fuel, determined in the same way as on the six hours' runs, was found to be 3·74-lbs. per I.H.P. per hour. On a previous trial of 1¾ hours' duration, as a check upon which the present trial was ordered, the consumption of fuel had been calculated at 3·42-lbs. The steam is supplied from ordinary double-flued mill boilers, and upon subsequent evaporation trials of one of the boilers at atmospheric pressure it was found that the weight of water evaporated per lb. of fuel from 100° was 9·103-lbs., when burning 17·53-lbs. of fuel per

* See page 12.

† It may be remarked, however, that there is no reheater as in the *Briton*.

square foot of grate per hour, the estimated rate of combustion, as will be seen above on the trial, having been 17·8-lbs.

As will also be seen, the total weight of steam or water, as measured, was 18·92-lbs. per I.H.P. per hour. This would give only 5·59-lbs. of water evaporated per lb. of fuel by the boiler, the lowest evaporative trial of which at atmospheric pressure gave 7·843-lbs. The coal used on all the trials was of first-rate quality, and its evaporative power when tried in the marine test-boiler was found to be 9·635-lbs. of water from 100° per lb. of fuel.

There are two things which are probable here—first, that the coal per H.P. as calculated is too high; and second, that the weight of steam per H.P., as measured, is too low. It would be impossible to fix accurately the weight of steam and fuel actually used, but making the liberal allowance of one-fourth, or 25 per cent. for error, we have 2·82-lbs. of coal per I.H.P. per hour as the probable consumption for an engine of the *Briton* type, driven by ordinary Lancashire boilers, using the best Welsh coal, the probable rate of combustion being then only 13·35-lbs. per square foot of grate per hour, and if we assume that 8-lbs of water were evaporated by the boiler per lb. of fuel we have 22·56-lbs. of steam per I.H.P. per hour used by the engine.

These figures coincide with those given by Messrs. LORING AND BAKER for engines of this type, in the Report to the Secretary of the United States Navy, quoted above. The gain over the simple engines working at 30-lbs. pressure having been calculated at 29·26 per cent., and the weight of steam used per I.H.P. at 22·46-lbs. per hour, it is remarked :—

" The indicated horse-power is the standard of comparison com- " monly employed in the current discussions of the performance of " compound engines, although the net power would afford the rational " standard. The gain of 29·26 per centum in the cost of the " indicated power is much less than that usually claimed for the " compound engines by persons interested in their manufacture. If, " as is often asserted, the indicated horse-power is obtained at a cost

"of only two pounds of coal per hour, the boilers employed must "evaporate 11·23 pounds of water per pound of coal. This quantity "is much greater than has ever been evaporated by boilers of the "types employed with the compound engines under consideration. "The quantity of water evaporated in such boilers per pound of coal, "at the high rates of combustion generally employed in English "practice, will be found not to exceed eight pounds of water from a "temperature of 100° Fahrenheit. When the apparent evaporation "is greater, the increase may be due to superheating the steam; the "results of which practice would be equally advantageous in the "case of engines of either type. The cost of the indicated horse-"power, then, in lbs. of coal per hour would be $\frac{22·46}{8} = 2·81$."

Thirty trials of Welsh coal from the best beds conducted at Keyham in 1871, gave as a mean result 9·427-lbs. of water evaporated from 100° per lb. of fuel, the test-boiler being of the ordinary marine type and the coal being burnt with the greatest possible care. The highest mean of five trials was 9·72-lbs. and the lowest 9·237. For ordinary practice at sea the figure of 8-lbs. taken by the American engineers is therefore probably correct, $9\frac{1}{2}$-lbs. at the very outside with the best Welsh coal being probably evaporated with clean boilers at low speeds.

It would seem that the figure of 2·4-lbs. per I.H.P. per hour given for the *Briton* type burning about 20-lbs. of coal per square foot of grate is, if anything, under the mark, and, judging from the above particulars and the American experiments it appears to be highly improbable that any of the compound marine engines now in general use and working with steam under similar conditions to the engines of these ships, have ever really worked at sea with less than 2-lbs. of coal per I.H.P. per hour, although results ranging from something like 1-lb. per I.H.P. upwards are constantly given for them, the coal used in many cases being of kinds capable only of evaporating 7 to 8-lbs. of water under the most favourable circumstances.

Some 25 years ago experiments conducted by the late Mr. EDWARD HUMPHRYS, at Woolwich Dockyard, in which the weight of feed

water used per H.P. per hour was carefully noted, showed that there was a positive loss in attempting to work with any degree of expansion in the unjacketed, slow-going, large-cylindered, geared engines in use in the British Navy at that time and adopted in the American Navy in some cases up to a recent date. The well-known experiments of ISHERWOOD, conducted by the United States Navy Department during the Civil War, under circumstances which reflect the highest credit upon the Americans, who thoroughly appreciated the importance of the questions at issue, also clearly showed the futility of attempting to obtain the most economical results with saturated steam expanded in unjacketed cylinders with low velocity of piston. ISHERWOOD'S experiments were made with unjacketed cylinders partially covered with felt, the ends and slide casings being unprotected. The particulars of the trial of the *Mackinaw* with saturated steam may be taken as a fair sample of the results of these experiments, from which it was shown that at the pressure then in use the consumption of steam per indicated horse-power gradually decreased up to a cut-off of about ·35 and then gradually increased at the higher grades of expansion.

MACKINAW.

Date of trial	1864
Diameter of cylinder	58-ins.
Length of stroke	8-ft. 9-in.
Velocity of piston, feet per minute	126
$\frac{\text{Clearances}}{\text{Effective capacity of cylinder}}$	·084

Cut-off	·70	·56	·38	·21
Boiler pressure above atmosphere ... lbs.	27	28	35	38
Absolute initial pressure in cylinder lbs.	41·32	43·0	49·0	53·0
Feed water used per I.H.P. per hour lbs.	32·913	30·628	30·31	36·04
Proportion of feed water accounted for by the indicator	·9254	·8857	·7818	·6218

The investigations of JOULE, RANKINE, and others, had previously shown that liquefaction necessarily followed the performance of work during the expansion of saturated steam, while experience with the

locomotive and experiments by Messrs. PENN and other leading engineers, had proved the necessity for providing against the losses from condensation, and had indicated the utility of the jacket (first used by WATT) superheating and high velocity of piston as means of prevention. In the earlier iron-clads unjacketed cylinders continued, however, to be fitted, and superheating was not resorted to, but in Mr. REED's ships the jacket was introduced, partially superheated steam was used, and the velocity of piston was gradually increased until in the *Sultan*, engined by Messrs. PENN, a mean speed of 650 feet per minute was obtained on her six hours' trial at sea. The unprecedented power of 9000 horses was thus developed, a result, which, having regard to the weight and space on which it was obtained, was viewed by French Engineers accustomed to the heavy lumbering framing of their own engines, with almost as much incredulity as the co-efficients of French ship performance are regarded by English designers. There can be no doubt that such a speed of piston with a trunk engine, occasioned loss of efficiency from friction, and this should be borne in mind in connection with the comparatively low co-efficients of the short English iron-clads, but the enormous power developed enabled a speed of ship to be obtained which, under the conditions, would probably have been impossible of attainment otherwise.

Referring now to the recent American experiments, it will be seen that they generally corroborate Mr. ISHERWOOD's results, and one noticeable feature will be found to be the low speed of piston as compared with English practice. Below are abstracted from *Engineering* the leading particulars of the principal trials of the U.S. Coast survey steamer, *Bache*. The trials were conducted by Mr. EMERY, the designer of the engines.

The Engines of the *Bache* are compound. They have two cylinders, a small one being placed on the top of a large one as in Messrs. HOLT's engines and the engines of the White Star Line. Provision is made for taking the steam direct from the main steam-pipe into the lower cylinder which can then be worked as a simple engine. The

BACHE.

—	Compound, using steam-jacket, and draining intermediate chamber.		Simple engine without using steam-jacket.	Simple engine using steam-jacket.	Compound, without using steam-jacket but draining intermediate chamber.
Number of trial for reference ...	8	9	13	16	3
Diameter of cylinder { High—ins. Low—ins.	15·98 25	15·98 25	25	25	15·98 25
Stroke of pistons .. ... ins.	24	24	24	24	24
Date of trial	May 14, 1874	May 15, 1874	May 18, 1874	May 18, 1874	May 14, 1874
Duration of trial ... ... hours	7·066	15·233	2·05	2·116	2·133
Mean steam-pressure in boiler—lbs.	79·96	79·7	78·11	79·5	80·31
Ratio of expansion	5·707	5·097	5·32	5·11	5·634
Mean vacuum in condenser ins.	26·11	24·39	24·22	25·52	24·656
Mean No. of revolutions per min.	55·59	53·62	47·07	53·84	49·265
Initial pressure in cylinder above atmosphere	H.P. 75·32 L.P. 8·96	74·47 7·52	72·75	76·1	73·00 3·9
Absolute initial pressure in cylinder	H.P. 90·04 L.P. 23·68	88·78 22·83	87·39	90·74	87·72 18·62
Mean effective pressure lbs.	H.P. 45·37 L.P. 13·96	43·06 14·908	32·328	36·94	45·137 11·2756
Estimated friction-pressure lbs.	H.P. 0·75 L.P. 2·25	0·75 2·25	2·25	2·25	0·75 2·25
Indicated horse-power	106·028	102·263	89·1	116	85·81
Effective horse-power	97·7	94·2	82·9	109·37	78·447
Steam per I.H.P. per hour lbs.	21·9661	22·3798	26·247	23·154	23·21
Steam per effective H.P. per hour, lbs.	23·8385	24·287	28·21	24·56	25·3887
Coal per I.H.P. per hour ... } Calculated for evaporation of 9-lbs. water per lb. of fuel. lbs.	2·441	3·487	2·917	2·573	2·579
Coal per effective H.P. per hour } Calculated for evaporation of 9-lbs. water per lb. of fuel. lbs.	2·649	2·699	3·134	2·729	2·821
Effective capacity of cylinder cubic feet per I.H.P. per minute ...	H.P. 2·9 L.P. 7·1	2·9 7·1	7·2	6·3	30·199 7·811
Velocity of piston per minute ft.	222	214	188	215	197

low-pressure cylinder only is jacketed, as in the *Briton*, and the expansion is regulated by adjustable cut-off plates at the back of the main slide.

Diagrams from this engine have been published in *Engineering* of March 5th, and from these it appears that no attention whatever was paid to cushioning in the exhaust. As stated on page 25, it is essential to economy in the simple expansive engine that cushioning should be provided for. The economy from this source appears to be due to two causes:—First, to the direct saving of steam; and second, to the heat generated in compression, which tends to prevent the liquefaction of the incoming steam. In the locomotive, although the ports are large on account of the high velocity of piston, the extensive compression which necessarily attends expansion by the use of the link provides against the loss which would otherwise take place; and there is apparently ample evidence that locomotives, although non-condensing, work on a consumption of fuel which will compare most favourably with the marine compound engines at present in use.

Again, the low velocity of piston was entirely in favour of the compound engine, in this case, as the loss which takes place by the 'worrying' of the steam through the intermediate passages between the upper and lower cylinders was not so great as it would be at the speed at which engines are ordinarily worked at sea. *

The lowest consumption of steam registered for the *Bache* per effective horse-power when working "compound" and using the jacket was 21·9989 at a ratio of expansion of 5·752. This trial was of less than two hours duration however, and a seven hours' trial at the same rate of expansion has been selected for comparison above as being more trustworthy. It is marked No. 8.

*The indicator furnishes ample evidence of the loss which takes place in this type of compound engine. Arranged with four cylinders for large powers, it however, undoubtedly possesses for commercial steamers many advantages over the type of compound engine with two cylinders side by side and having cranks at right-angles; the principal being probably, somewhat less liability to racing in a sea-way, more manageable dimensions of cylinders, and equal distribution under all circumstances of the power transmitted to the two cranks.

The trials of the engine when the large cylinder only was used as a simple engine were all unfortunately of short duration, the trial, No. 13 quoted in the table, being the longest. It is not evident whether the maximum efficiency of the steam had been reached at the ratio of expansion of this trial—5·11, but the probability is that in the absence of cushioning it was, or nearly so. At the next grade of expansion tried, 8·57, there was a loss, the weight of steam used being 26·23-lbs. per effective horse-power against 24·56 at ratio 5·11. Comparing this latter figure with 21·9989 given for the short trial of the compound engine above referred to, a gain of 10½ per cent. is shown for the compound engine, but if the seven hours' trial (No. 8 quoted in table) at the same ratio of expansion 5·707—be used for comparison, the gain diminishes to 3 per cent., while if the 15 hours' trial with ratio of expansion 5·097 (No. 9 in table above) be taken for comparison, the gain practically disappears, the figures then becoming—jacketed compound engine 24·287; simple jacketed engine 24·56.

Again, when the jacket was not in use in the compound engine the least weight of steam used per effective H.P, was 25·39-lbs. (trial No. 3, see table above), the ratio of expansion being 5·634 and the maximum efficiency having then been reached. The weight for the simple engine being 24·56-lbs., the result here is that a simple jacketed engine might be expected, even under unfavourable circumstances, to be more economical than the engines of the White Star Line and other most successful compound engines in which the jacket has been dispensed with entirely. Had the velocity of piston been higher in both cases, and had the simple engine been properly cushioned, the result would have gone still further against the compound engine.

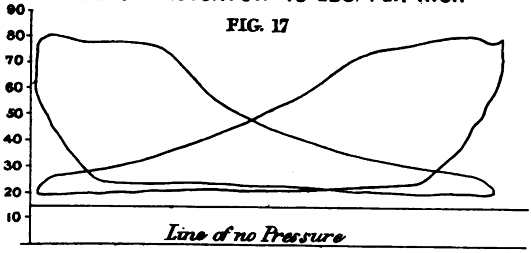
As might have been expected from the entire absence of cushioning, leaving out of the question other causes of loss, the consumption of steam per horse-power increased more rapidly in the jacketed simple engine than in the jacketed compound at the higher grades of expansion, but with the jacket of the compound not in use the consumption was about the same as in the simple as will be seen here :—

	Simple, jacketed.		Compound.			
			Not jacketed.		Jacketed.	
Ratio of expansion	8·57	12·62	6·658	9·146	9·19	16·85
Weight of steam per effective horse-power ... ... lbs.	26·23	29·99	25·427	26·825	22·81	28·698
Duration of trial ... ... hours	1·683	2·10	2·066	1·833	2·066	1·73

The experiments with the Revenue steamers are of the greatest interest if only for the admirable manner in which they were conducted, and the report of the engineers in charge has been reproduced in full at the end of this appendix. Unfortunately, however, the simple engine in this case was not jacketed and no direct comparison can therefore be made. The whole of the experiments have recently been discussed in a series of interesting articles published in *Engineering*, and in the number for February 19th last, a gain in economy of 12·65 per cent. by the use of the jacketed compound engine is shown as compared with the jacketed simple engine. This result is obtained by basing the comparison on the indicated horse-power, and by assuming that the consumption of steam would have been reduced in the *Dexter* in the same proportion as in the *Bache* by the use of the jacket. The two trials of the *Bache* selected for the comparison are Nos. 13 and 16, the results of which are given in the table above, and from these it appears that a gain of 11·78 per cent. was due to the jacket in the simple engine. Assuming then that a gain of 11·78 per cent. would have been obtained in the *Dexter* trial No. 3 by jacketing, and comparing this trial with the *Rush* trial No. 1 the gain of 12·65 per cent. is shown in *Engineering* by Mr. Emery, the designer of the compound engines of the *Rush*. Mr. Emery also shows a saving of 12·19 per cent. in favour of the jacketed compound engine in the *Bache*, the trial selected for comparison being the short trial of under two hours' duration referred to above. As already pointed out with regard to the *Bache*, the seven hours trial at the same rate of expansion as this short trial showed a gain of 3 per cent. only in steam per effective horse-power, and in the 15 hours' trial the gain had disappeared.

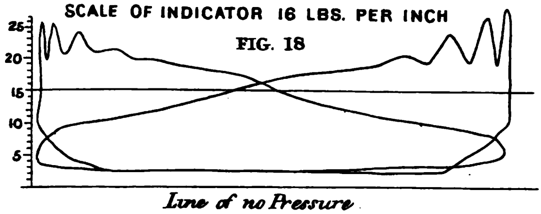
U. S. REVENUE STEAMER "RUSH"
HIGH PRESSURE CYLINDER.
SCALE OF INDICATOR 40 LBS. PER INCH

FIG. 17



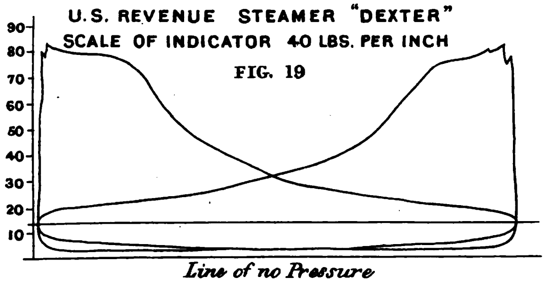
LOW PRESSURE CYLINDER
SCALE OF INDICATOR 16 LBS. PER INCH

FIG. 18



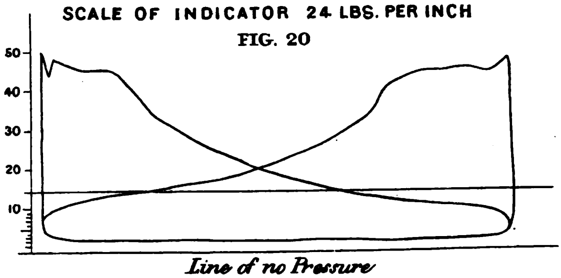
U. S. REVENUE STEAMER "DEXTER"
SCALE OF INDICATOR 40 LBS. PER INCH

FIG. 19



U. S. REVENUE STEAMER "DALLAS"
SCALE OF INDICATOR 24 LBS. PER INCH

FIG. 20



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An indirect comparison based on the data available for the *Dexter* and *Rush* must in any case be a dubious one, but the gain of 12·65 per cent. shown by Mr. EMERY can hardly be taken as most probably representing the real gain in economy. As pointed out in the report of Messrs. LORING and BAKER before quoted, the effective, or as termed by the Americans the "net" horse-power, should be used as the standard, and as it is given in the results of these trials, in all cases, comparisons for absolute economy should certainly be based upon it.

Taking therefore the long run of the *Dexter* (trial No. 5) as being the most trustworthy and assuming that the consumption of steam per effective horse power would have been decreased in the same proportion as in the *Bache* (trials Nos. 13 and 16) by the use of the jacket, it will be found that the gain shown for the compound engine would be $9\frac{1}{2}$ per cent., the ratio of expansion being 6·215 in the *Rush* and 3·489 only in the *Dexter*. The gain in the *Bache* (jacketed simple engine) by increasing the ratio of expansion from 2·18 to 5·11 was 32 per cent., the probability being that in the absence of cushioning the maximum efficiency was reached at this point or very little beyond it. Referring to the diagrams for the *Dexter*, fig. 19, it will be seen that here as in the case of the *Bache* there was no attempt at cushioning in the exhaust. The probability is evidently that if the *Dexter* had been worked at the higher grade of expansion and properly cushioned, the $9\frac{1}{2}$ per cent. gain would have decreased considerably if it had not disappeared as in the case of the *Bache*, where it had practically disappeared even under unfavourable conditions.

There are many lessons to be learnt from these trials into which it is not necessary to enter here. So far as the relative economy of the two types of engine, when worked at the same pressure is concerned, the results may be summarised as follows :—

Description of Engine.	*Bache.* Compound, jacketed.		*Bache.* Simple. Not jacketed.	*Bache.* Simple. Jacketed	*Bache.* Compound, not jacketed.	*Rush.* Compound, jacketed.	*Dexter* Simple.
No. of trial for reference...	8	9	13*	16*	3	1	5*
Total effective capacity of cylinder, cubic feet per I.H.P. per minute ...	10	10	7·2	6·3	11·01	13·18	6·2
Velocity of piston per minute .. ... feet	222	214	188	215	197	319	366
Steam per effective H.P. per hour ... ... lbs.	23·838	24·287	28·21	24·56	25·39	20·4656	22·62
Coal per effective H.P. per hour, calculated for evaporation of 9-lbs. of water per lb. of fuel	2·649	2·699	3·134	2·729	2·821	2·273	2·51
Ratio of expansion ...	5·707	5·097	5·32	5·11	5·634	6·2157	3·489
Boiler pressure	79·96	79·7	78·11	79·5	80·31	69·06	68·70

* No allowance made for want of cushioning in these three cases. *Dexter* assumed to be jacketed, but difference between grade of expansion and that of *Rush* not allowed for.

Engineers accustomed to weigh matters of this kind from a practical point of view will draw their own conclusions from the facts and figures given. They appear to the writer to show that practically the same results in point of economy may be obtained with either type of engine when the same pressure of steam is used, and that in well-handled engines of good design, the maximum efficiency of the steam will be reached at about the same grade of expansion. The engines were too small in any case to allow of a trustworthy conclusion being arrived at as to the point at which expansion ceases to be economical in the large marine engines at present in use, and in the simple engine the unfortunate absence of cushioning introduced an element of inefficiency which might have easily been avoided. On the low power trials of the *Swinger* the importance of using the link so as to lessen the loss from the clearances† was quite understood, and it is evident that in this way expansion can be carried to a greater extent

† The ratio of clearances to effective capacity of cylinder was ·0914 in this case.

economically than was the case in the American trials. These trials cannot therefore be taken as good evidence of the desirability or otherwise of providing in simple engines for working "compound" at low speeds. With three cylinders of equal diameter the results obtained by the use of two of them as low-pressure cylinders could not be expected to be so economical as with a compound engine having high and low-pressure cylinders of the proportion of those of the *Bache* or *Rush.* It appears to be probable that by using the link at the higher ratio of expansion the use of two out of the three cylinders, as proposed in the Essay, with single expansion would be found more economical, and the complication introduced in the "composite" engine would be avoided.

The difficulties* which have been met with in the use of the high-pressure simple expansive engine in the Merchant Service appear invariably to have arisen from the valve gear, and it is exactly these difficulties Messrs. PENN are prepared to meet on the largest scale and which Messrs. HUMPHRYS appear to have completely overcome in the *Swinger.* The failures which have occurred in the Merchant Service are, however, certainly not encouraging to ship-owners. The CORLISS engines of the *Circassian*, referred to in the essay, after having run for some time with undoubted economy proved unsatisfactory, and the ship having to be lengthened the opportunity has been taken to compound the engines, a contingency provided for in the original design. Another of the Transatlantic lines appear to have had a similar experience. The North German Lloyd's Co. have, on the other hand, met with fair success in the application of the principle, having tried it on a considerable scale. Four of the ships of this company, the *Bismarck*, *Koln*, *Kron Prinz*, and *Kœnig Wilhelm*, were fitted with

*The strangest objection yet seriously urged against the simple engine, with which the writer is acquainted, is, that owing to the variation of the driving force a molecular change of a grave character rapidly takes place in the constitution of the shafting, the metal becoming crystalline. A glance at the torsion diagrams for the compound engines, C and D, figs. 13 and 15, will be sufficient to show that as far as variation of strain is concerned, the shafts of some of the most successful compound engines should long ago have succumbed to this form of deterioration. Crystallisation, it may be remarked, is usually found associated with materials of dubious quality, and does not appear, for all practical purposes, to affect sound Yorkshire iron, for example, even when used in situations most favourable to crystallisation, as in the case of steam hammer piston rods.

simple expansive engines of 1600 indicated horse power in 1871, by Messrs. CAIRD, the boiler, pressure being 60-lbs. Some difficulties appear to have been met with in the first instance from the failure of the thrust-shafts, which were made of puddled steel. Two broke and the other two also showing flaws from defective forging they were removed. The engines, which have twin cylinders of 48 inches diameter and 4-ft. stroke, are still at work with single expansion, and two of the ships have just been supplied with new cylindrical boilers by EARLE'S Shipbuilding and Engineering Co. The consumption of fuel in the vessels is, the writer has been informed, from 28 to 34 tons per 24 hours for a speed of 11 to 12 knots, and compares favourably with that of other ships of the Company of nearly similar dimensions, fitted with compound engines, and which burn from 35 to 40 tons at a speed of from 12 to 12½ knots.

For the Commercial Marine, and especially for the Mail Service, the simple engine, although requiring greater care and intelligence in handling, offers, at present pressures many advantages, and notwithstanding the failures which have occurred, the causes of which would be avoided in future designs, it will no doubt receive further trial.

For ships of war, even at higher pressures, it is probable that the 3-cylinder simple engine would be found most suitable, judging from the most recent experience with the locomotive, and from its being apparently the fact that the maximum efficiency of the steam is reached even with the locomotive pressure at a ratio of expansion easily attainable in a single cylinder. Mr. WEBB, Mr. RAMSBOTTOM'S enterprising successor at Crewe, has in his latest express locomotives attained a speed of piston of nearly 1200 feet per minute, with only a 2-feet stroke. After this and the experience with the trunk engines of the *Sultan* at 650 feet per minute, a speed of 800 to 1000 feet per minute need hardly be regarded with much trepidation. With such a speed of piston, the locomotive pressure, and forced draught obtained from powerful blowers, it is pretty evident that the propelling power could be produced on something like one-third of the weight of the compound engines at present in use, and in a space which would

admit of the machinery being effectually protected from attack above water. As already pointed out, the active corrosion which takes place at high pressures is the principal difficulty in the way of introducing machinery of this kind. For some classes of armoured ships, (vessels for coast and harbour defence for example), and also of unprotected vessels the difficulties from this source could, however, be overcome by known means to an extent sufficient for all practical purposes, and there can be no doubt that the adoption of machinery of this type, advocated by Mr. BRAMWELL and other Engineers of the highest eminence, is well worth consideration.

Report of the trials of the steam-machinery of the United States revenue-steamers 'Rush,' 'Dexter,' and 'Dallas,' at the United States navy-yard, Boston, Mass., in the month of August, 1874, by a joint board of United States naval and United States revenue-marine engineers.

IN the early part of the present season there were completed, for the United States revenue-marine, three new revenue-steamers, named, respectively, in honor of ex-secretaries of the Treasury, the *Rush*, the *Dexter*, and the *Dallas*. The three vessels are similar as respects the hulls, the screws, and the boilers, but the engines are different each from the other: that of the *Rush* being a compound engine; that of the *Dexter*, a high-pressure condensing-engine; and that of the *Dallas*, a low-pressure condensing-engine.

The vessels are each 140 feet long over all, 129½ feet between perpendiculars at water-line, 23 feet extreme breadth of beam, and 10 feet depth of hold. The draught of water aft is about 8 feet 10 inches. The hulls are of wood. The vessels represent the smallest type of full-powered screw revenue-cutters adapted for cruising-purposes. They were all intended to be rigged as schooners; but it having been decided to send the *Rush* to the Pacific coast, she was rigged as a top-sail schooner. One of the vessels averaged upward of eleven nautical miles per hour for six consecutive hours on her trial-trip, and neither of them averaged less than 10 knots; the machinery being entirely new in each case.

Each vessel has one boiler, 11 feet wide on base and 9 feet high, with a double segmental shell, each portion being 6 feet 2 inches in diameter. There are three furnaces in each boiler, located between water-legs attached to the bottom of the shell. The products of combustion return through tubes within the shell. The boiler of the *Dallas*, designed for low-pressure steam, is 13 feet 9 inches long, the front connection being built in and the steam-chimney attached to the boiler. The boilers of the two other vessels were designed for high-pressure steam, and are each 12 feet long, independent of front connection, which is a separate structure bolted on. The steam-chimney is also a separate structure, connected to the boiler by a large tube. The boiler of the *Dallas* has 160 tubes, $3\frac{1}{4}$ inches in diameter and 9 feet 3 inches long. The boilers of the two other vessels have each 158 tubes, $3\frac{1}{4}$ inches in diameter and 9 feet 8 inches long.

The *Rush* is propelled by a compound engine with vertical cylinders and intermediate receiver, arranged fore and aft at the same level, the pistons being separately connected to cranks at right angles.

The cylinders are thoroughly steam-jacketed, felted, and lagged, and are respectively 24 and 38 inches in diameter, with 27 inches stroke of piston. The steam is distributed to the high-pressure cylinder by a short slide-valve, with adjustable cut-off plates sliding on back of same. The distribution of steam to the low-pressure cylinder is effected by means of a double-ported slide-valve, with lap proportioned to cut off the steam at about half-stroke. The surface-condenser is arranged on the starboard side. It supports two main columns from the cylinders, and contains 900 square feet of condensing surface. The air-pump is operated from the cross-head of the low-pressure engine. The circulating-pump is of the centrifugal type, operated by a small engine directly connected. The screw is 8 feet 9 inches in diameter, with mean pitch of $14\frac{1}{2}$ feet. The engine was intended to be operated regularly with a steam-pressure of 80 pounds, but during the trials, hereafter referred to, it was reduced to correspond to the pressure carried on trial of *Dexter*. The machinery was designed by Charles E. Emery, consulting engineer,

and built by the Atlantic Works, East Boston, Mass., the contractors for the vessel complete.

The *Dexter* was also built under contract with the Atlantic Works, East Boston, Mass. The engine of this vessel is built from designs of that establishment, and is of the inverted type, with a single cylinder, 26 inches in diameter and 36 inches stroke of piston. The cylinder is not jacketed, but is carefully felted and lagged. Steam is distributed by a short slide-valve, with adjustable cut-off plates sliding on back of same. The condenser is located outside the frame, but it and the air and circulating pumps are exact duplicates of those in the *Rush*. The engine and boiler are designed to be operated with a maximum steam-pressure of 70 pounds.

The *Dallas* was built under contract with the Portland Machine Works, of Portland, Me. The engine was designed in that establishment, and is of the inverted type, with a single cylinder, 36 inches in diameter, with 30 inches stroke of piston. The cylinder is not steam-jacketed, but is carefully covered with non-conducting composition, and lagged. Steam is distributed by a short slide-valve, with adjustable cut-off plates sliding on back of same. The surface-condenser is located under starboard frames, and has the same condensing-surface as those in the other vessels. The air and circulating pumps are also substantially the same. The engine and boiler are designed to be operated with a maximum steam-pressure of 40 pounds.

The opportunity presented of testing in these vessels the relative merits of the three kinds of engines attracted considerable attention. Several manufacturers and engineers expressed a desire that competitive trials be made. A correspondence on the subject was opened between the Navy and Treasury Departments, which resulted in an agreement for a trial, under the direction of persons representing both services, and the undersigned, Chief Engineer Charles H. LORING, U.S.N., and Charles E. EMERY, consulting engineer, were selected in behalf of the Navy and Treasury Departments, respectively, to make preparation for and take general charge of the trials.

* * * * * * * * * *

MANNER OF MAKING THE EXPERIMENTS.

The experiments were made with the vessels secured to the wharf. The coal, which was anthracite, of fair quality, was broken on the wharf to proper size, (the vessel's bunkers having been closed and sealed,) and filled into bags to a certain weight. The bags were sent on board when ordered by the senior engineer on watch, he making record on the log of the number of bags and the time of receipt, a similar record being made by one of the men on the wharf. At the end of the hour the number of bags of coal actually put on the fire was reported from the fire-room and entered in the appropriate column. The several records agreed with each other, and the total amount expended corresponded with the total number of bags filled on wharf. The ashes were measured into buckets (of which the mean weight was ascertained) and tallied as they were hoisted out. They were afterwards weighed in gross on the wharf, and the two accounts found to agree substantially.

The feed-water was measured after its delivery from the surface condenser and before its return to the boiler, for which purpose a tank of boiler-plate was especially constructed, having a plate dividing it vertically into two equal parts. In the upper edge of the plate was cut a rectangular notch eight inches long, by which the height to which each half of the tank could be filled was determined. The mean of the weight of water which the half-tank contained was $1129\frac{1}{2}$ pounds, at a temperature of 72 degrees Fahrenheit.

In the computations for each experiment, the weight of water is reduced to correspond with mean temperature.

One of the feed-pumps was disconnected from the check feed-valve, and its discharge-pipe led to a small receiving-tank placed over the two halves of the measuring-tank, into which this pump forced the condensed water from the hot-well. The receiving-tank had on its bottom two cocks, one over each half-tank, so that either could be filled from it at will. The other feed-pump had its suction-pipe

detached from the hot-well, and connected with the bottoms of the two half-tanks through a cock on each, so that the contents of either could be drawn out and discharged into the boiler.

The method of measuring the water and recording it was as follows: One side having been filled, the cock over it on the receiving tank was closed and the other over the empty half opened. When the water in the full one had settled to the height of the edge of the notch, its cock in the feed-pipe was opened and the contents pumped into the boiler, (care being taken to empty one in less time than it required to fill the other). When empty, its feed-cock was closed. When the water in the tank being filled reached within a few inches of the notch, a gong in engine-room was sounded to call attention, and when it reached the notch the gong was struck twice; at this instant the assistant engineer in the engine-room noted the reading of the counter, and an attendant in the fire-room noted and reported the height of water in the glass gauge on boiler, as shown by a scale of inches secured to it. The attendant at the tank also noted the time of filling and the temperature when the tank was half emptied. After entering the number of the counter in the log, the assistant engineer ascertained the numerical difference between that and the preceding entry, and, if it was far from the average, its cause was sought for.

By this system of checks all errors of record could be detected, and it was possible to preserve and utilize any continuous run which came to an end through derangement of the engine. All parts of the tanks, pipes, and cocks were plainly visible to the eye; and had any leaks occurred therein, they must have been detected. That the condensers were tight was evident from the fact that the water remained quite fresh in the boilers.

The water lost from ordinary causes in the circulation to and from the engine and boiler was replaced by running hydrant-water in the tank that was being filled. The additional water was therefore measured and charged in the cost.

The loss of water was not sufficient to affect the result materially

in either case. It was greatest in the *Dexter*, which had been on service. The safety-valve of this vessel leaked slightly, and there was probably some other trifling leak that could not be detected. The number of inches that the water fell in the boiler between periods of supply, being shown in the logs, were added together, and from the same and the known dimensions of boiler, the volume and weight lost were ascertained quite accurately. The reduction in the number of revolutions per tank, when the water was being received from the hydrant, furnished another, and, perhaps, still more accurate, means of ascertaining the proportionate amount lost and returned. The two methods closely agreed in fixing the loss in the case of the *Dexter* at 4·96 per cent. of the total amount of water used.

A number of indicators were tested with steam before the trials, and a pair selected for use which proved correct by a standard gauge at varying pressures. Indicator-diagrams were taken every twenty minutes throughout the trials, and the data of the usual columns of the log (except the coal and ashes) every half-hour.

It was ascertained that the pistons of the *Dexter* and *Dallas* were tight by removing the cylinder-covers and letting on full steam-pressure.

During the first and principal experiments with each vessel, the several boilers were worked at their maximum power with natural draft at the dock, the fires being cleaned regularly as at sea, and the cut-offs adjusted to carry a steam-pressure of about 70 pounds during trial of *Rush* and *Dexter*, and about 35 pounds during trial of *Dallas*.

At the conclusion of the principal experiments on each vessel, shorter experiments, designated in the table by letters, were made to determine the effect of varying the degree of expansion at the approximate steam-pressures of 70 and 40 pounds. In the case of the *Dexter*, the cut-off was shortened for one experiment as much as the gear provided would permit, and for this vessel as well as for the *Dallas* the cut-off was gradually lengthened during other experiments as far as the boiler would supply steam at the pressure desired.

The long runs having demonstrated the evaporative qualities of

the boilers, record is made during the short runs of the amount of water used only; from this, the quantity of coal necessary to evaporate it can easily be obtained. It would have been impossible to distribute properly the coal consumed during the short runs, which followed each other immediately; while these runs were in progress, an officer was stationed at the tanks and one in the fire-room, in addition to the usual number on watch, to avoid the possibility of error.

In the annexed table we have endeavoured to show accurately, in condensed form, the results of the trials of the particular machinery described under the particular conditions named.

The actual performances will be found in the lines 53 to 68, inclusive, of the table; the previous lines showing the several observed and computed quantities from which the performances were calculated.

As previously stated, the boiler, during the principal experiments on each vessel, was operated at maximum power, and the results show that the evaporation was fully equal to that obtained in ordinary practice; but inasmuch as on land, and occasionally in steamers where space will permit, it is the practice to use a slower rate of combustion in comparatively larger boilers, thereby increasing the evaporative effect, there has been added to the table, for comparison under such circumstances, lines 69 and 70, showing the performances, compared on the basis of the water actually used, but with boilers of such proportions or using such variety of fuel that the evaporation will equal nine and ten pounds respectively per pound of coal.

The relative performances, shown decimally in lines numbered 73 to 80, inclusive, with different experiments as unity, will be found convenient for comparison.

It is believed that the other portions of the table will be fully understood without discussion or further explanation on our part.

CHAS. H. LORING,
Chief Engineer, U. S. N.
CHAS. E. EMERY,
Consulting Engineer, U. S. R. M.

NEW YORK, *October* 10, 1874.

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